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ANALYSIS OF PRODUCTION LEAD TIME FOR MISSILE REPAIR PARTS: CONTRACTS DEALING WITH CABLE ASSEMBLIES AND WIRING HARNESSES

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ANALYSIS OF PRODUCTION LEAD TIME FOR MISSILE REPAIR PARTS: CONTRACTS DEALING WITH CABLE ASSEMBLIES AND WIRING HARNESSES

Joseph S. Hill

Army Materiel Command
Texarkana, Texas

April 1975

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This investigation was undertaken to help in the development of a mathematical model for predicting production lead time on missle repair parts contracts dealing with cable assemblies and wiring harnesses.

Techniques of regression analysis and graphical analysis were employed on the data observations from thirty cable assembly and wiring harness contracts.

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The investigation reveals that total contract cost has the most significant influence on production lead time. Also, total contract cost has an even larger influence on production lead time when the data observations are regressed by interval ranges of unit cost per item. The best models were obtained using this procedure.

FOREWORD

The research discussed in this report was accomplished as part of the Product/Production Engineering Graduate Program conducted jointly by USAMC Intern Training Center and Texas A&M University. As such, the ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Department of the Army.

This report has been reviewed and is approved for release. For further information on this project contact: Professor T. F. Howie, USAMC-ITC-PPE, Red River Army Depot, Texarkana, Texas 75501.

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I am deeply indebted to Mr. William Blades of Redstone Arsenal in Huntsville, Alabama, and Mr. John C. Meyer, formerly of Redstone Arsenal, and now with Headquarters, U. S. Army Material Command in Alexandria, Virginia, for their conception of the problem, and their help in obtaining data for this analysis.

I also wish to thank Mr. Phillip Duvall and Mr. Patrick J. Hollifield, instructors in the Product/Production Engineering Graduate Program, Intern Training Center, for their help in the completion of this project.

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CHAPTER I

INTRODUCTION

The inability to accurately predict Production Lead Time (PLT) for items being produced or procured is one of the major problems faced today by customers and producers. This problem plagues private industry and the various governmental agencies responsible for providing equipment for the defense of our country. Management personnel at Redstone Arsenal (MICOM) in Huntsville, Alabama, are currently confronted with the late delivery of repair parts for their missle projects. This usually results in delays in the completion of the projects. Additional time and money must also be charged toward completion of the project. Management personnel at Redstone Arsenal feel that the production lead times written into repair parts contracts do not accurately reflect today's production environment.

Management does not have an accurate methodology to predict the PLT which should be written into their repair parts contracts with any degree of confidence. This information is needed to provide better planning and scheduling of the various projects, and to prevent severe schedule slippages.

Management has been able to make estimates for production lead times on limited types or categories of repair part items. These estimates have not always been satisfactory. Some of the problems in the past have occurred for two reasons. First, many of the items are purchased in small quantities. Second, the dollar amount of these contracts is small. It is felt that contractors tend to push these small contracts aside when larger or more lucrative contracts are obtained. This results in small contracts being given a low priority, and larger contracts a higher priority.

Data is available on the contracts that have been let over the past several years. However, this data is not in a usable form for decision making purposes. There is no vehicle currently available to successfully use this data to predict what the actual production lead times should be for the various repair part items needed in a particular missle project.

The purpose of this investigation will be to examine readily available past historical data to see if any trends exist that could possibly yield better estimates of PLT than those currently being used. A statistical

approach will be taken, and the data will be analyzed through techniques of Regression Analysis. (4)*

Redstone Arsenal currently has an inventory of over 8350 different repair parts for the various missle systems which they are responsible for. Personnel at Redstone have assigned these parts into one of the seventeen different groups, and have assigned each group a unique item code number. These seventeen group classifications are shown in Table 1, along with current estimates of the PLT for items within each group. The rationale behind these assignments assumes that items within each group possess similar physical and/or performance characteristics. It is assumed that the items within each group are similar enough to have approximately the same lead times for manufacture. The estimated PLT's shown in Table 1 were arrived at through years of experience in working with these items, and not through any statistical analysis. Many of the estimates are strictly guess estimates.

In this investigation, historical data from Group 04 of Table 1 was investigated. Raw data from thirty cable assembly contracts was obtained. None of these contracts fell into the category of "Blue Streak Procurements."

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*Numbers in parentheses refer to numbered references in the List of References.

Table 1 Group Codes and Current Estimates of Production Lead Times.

GROUP	PLT (Days)	DESCRIPTION
01	259 - 322	High Reliability Printed Circuit Boards (PCB)
02	203 - 266	Other PCB's
03	301 - 364	High Reliability Electronics Chassis
03.1	245 - 308	Other Electronic Chassis
04	259 - 322	Wiring Harnesses and Cable Assemblies
05	259 - 322	Wired Electrical Assemblies
06	168 - 224	Standard Electrical/Electronic Components
07	224 - 280	Special Electrical/Electronic Components
08	168 - 210	Waveguide Components
09	210 - 252	Electro-mechanical Assemblies (motors, Generators, etc.)
10	112 - 140	Machined Metal Parts
11	84 - 112	Non-metal Parts (Plastic, Rubber, Glass, etc.)
12	——	Omitted
13	196 - 252	Machined Castings and Forgings
14	168 - 210	Mechanical Assemblies
15	168 - 210	Hydraulic Assemblies
16	252 - 308	Optical Assemblies
17	84 - 112	Nuisance Items (Standard Nuts, Bolts, Paint, Packaging, etc.)

These are procurements which are urgently needed and are given special preference over other contracts in order to speed up their procurement. The variables which were investigated were: (1) quantity of purchase, (2) dollar amount of the contract, (3) unit purchase price per item, and (4) the actual PLT's of the contracts. Several other variables were considered for investigation, but due to the insufficient data available, were not included. These variables are discussed further in Chapter V in the Recommendations section.

Chapter II is the literature survey. This chapter provides a discussion of the various lead times associated with a government contract, and briefly summarizes previous studies on PLT.

In Chapter III a brief discussion is presented on the regression model employed. A description of IBM's Statistical Analysis System (SAS) computer program is provided.

Chapter IV details the various procedures and techniques employed in this investigation. Graphical and tabular results are presented.

Finally, the conclusions and recommendations are presented in Chapter V.

CHAPTER II

LITERATURE SURVEY

A Few Words About Lead Time

Before going into the literature survey, it is appropriate at this time to make a few remarks concerning the various lead times associated with government procurements. These lead times will be defined in the sequence in which they occur. This will convey to the reader, a better understanding of what will be discussed in the next section of this chapter.

Lead time in general may be defined as the period of time between the initiation of a procurement action, and the completion of that action. This definition is quite broad, and will now be specifically defined for the purposes of this study.

The two most important lead times of interest in a government procurement are Administrative Lead Time (ALT) and Production Lead Time (PLT). The sum of these two lead times makes up what is known as Procurement Lead Time (PRLT), which is the total time from initiation of the procurement action thru receipt of the final end-item. End-items are simply the individual items that are being procured such as printed circuit boards or hydraulic valves.

Administrative Lead Time is the time from initiation of a procurement action thru the signing of a production contract with a contractor. ALT begins with the release of DOD Form 1095. This document initiates the procurement of a specified end-item. During the ALT all the administrative work on the contract is prepared. ALT can vary from Ninety to One Hundred and Fifty days.

After a contract is awarded to a contractor, Production Lead Time begins. PLT is defined as the time from the signing of a contract thru the date of delivery of the end-item. PLT includes the administrative work which must be done by the contractor, the ordering and receipt of the raw materials necessary for the production of the end-item, the actual production time, and the delivery time to deliver the finished product to its designated destination. This may take from several months to several years depending on the complexity of the end-item.

In addition, if the procured end-item is expensive and complex, or if the contractor is manufacturing this item for the first time, a First Article production clause may be written into the contract. A First Article (F/A) is an exact working model of the end-item, which must be submitted to the government for inspection and testing, before further production may continue. This additional

time for F/A production and testing is included in the PLT, and occurs prior to full-fledged production.

Figure 1 depicts a diagram of how all of these individual lead times fit together to form PRLT. In the contracts that were studied, no F/A production was required.

The Search For Background Information

A search on the subject of Production Lead Time from published textbooks and reference books proved to be a futile effort. While the topic was mentioned briefly in some of these books, its coverage was completely inadequate for the purpose of this report.

Next, an inquiry on the topic of lead time was made to the Defense Logistics Studies Information Exchange (DLSIE) located at Fort Lee, Virginia. A Custom Bibliography was received from DLSIE with a summary of the contents of each report available. This bibliography was thoroughly examined, and about fifteen promising reports were ordered and carefully studied. Those reports not directly relating to the problem at hand, were discarded. The remaining four reports were examined, and will be discussed in the remainder of this chapter.

The first report is titled "Evaluation of Administrative Lead Time and Production Lead Time" written by

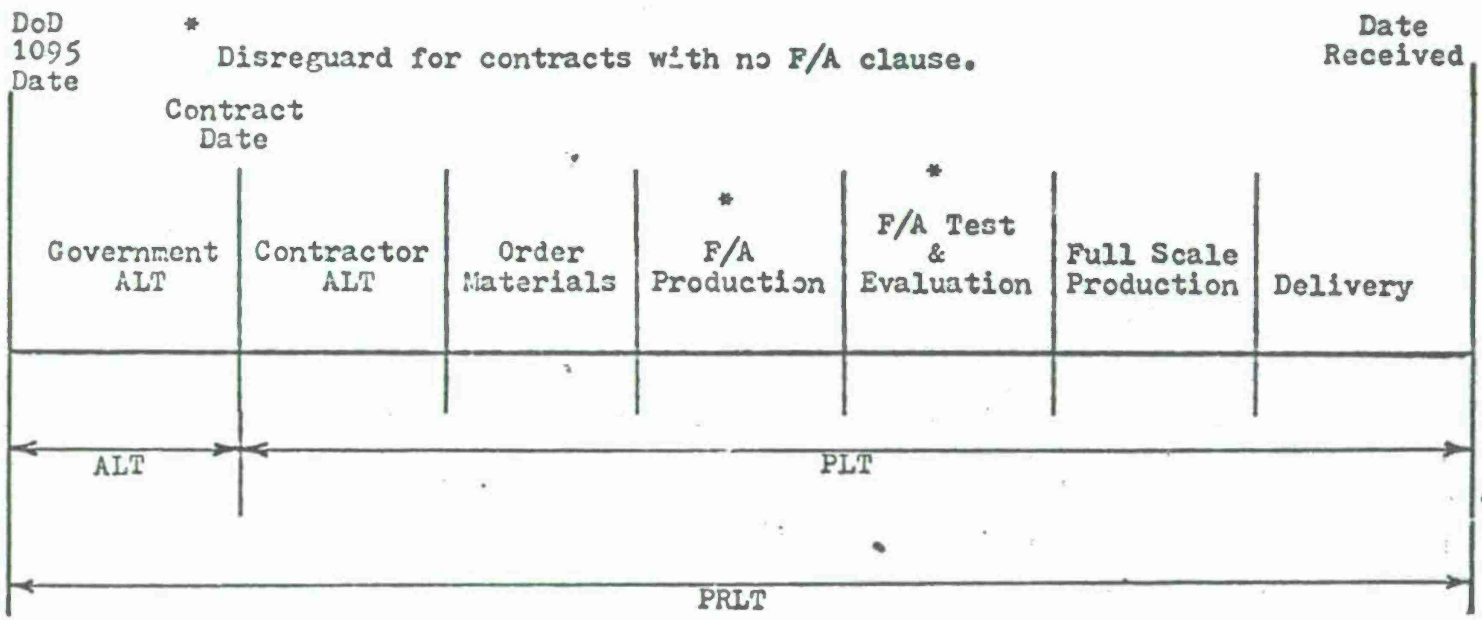

Figure 1 Distribution of the Various Lead Times in a Government Procurement Contract.

Aubrey A. Yawitz (8). He performed the study for the U. S. Army Troop Support Command (TROSCOM) in November, 1973. The purpose of his report was to determine at what point in time it is necessary to initiate a procurement action to replenish stock inventories at TROSCOM. His goal was to minimize zero balances, stockouts, delays in filling demands, and the prevention of overstockages. Yawitz used estimated ALT and PLT data, and compared it to the actual ALT and PLT that occurred. Using 87 High Velocity items in his data sample, he applied correlation and regression analysis, histogram construction, and computations of means and standard deviations, to come up with mathematical models for predicting lead times.

Yawitz concluded that there was no relationship between estimated lead times, and those that actually occurred. He also concluded that there was a great deal of lead time variability displayed in the items he studied.

The second report, also written by Aubrey A. Yawitz, is a companion report to the preceding report just mentioned. It is titled "Variability of Administrative Lead Time and Production Lead Time" (9). Yawitz, using his previous report as a foundation, set out to develop a model

to take the lead time variability into account, when predicting lead times for future contracts. Using averages, histograms, standard deviations, and regression equations, Yawitz was able to develop charts that would compensate for lead time variability with a desired level of confidence.

Yawitz concluded that lead time variability is considerable and measurable, and that charts can be constructed to give the decision maker some degree of confidence in predicting future lead times.

The third report is titled "Mean Lead Time" written by G. B. Bernstein (3). This study was conducted in July, 1964 for the Navy Fleet Material Support Office, Mechanicsburg, Pennsylvania. Bernstein tackled the problem of estimating the lead times for procurement of new items which had never been procured before.

New items were previously assigned a standardized lead time of one year. This assigned lead time was always the same, irregardless of how complex or simple the item was. Bernstein theorized that simple items should have shorter lead times, and more complex items longer lead times. Under this assumption, he divided up the Navy's total inventory of stock items into 100 categories, placing similar items together by nomenclature. He then computed the mean lead time for each of the 100 categories. Next,

a table was constructed with the 100 categories listed along with their associated mean times. The decision maker could then look up a new item to be procured in this table, and use the mean lead time as his estimate of the Procurement Lead Time.

Finally, the last report is titled "Production Lead Time Forecasting" (7) written by E-5 Lawrence Wheelock. This report was conducted in January, 1972, by the U. S. Army Logistics Management Center (ALMC) in cooperation with the U. S. Army Aviation Command (AVSCOM). The purpose of this study was threefold. First, examine currently used techniques of forecasting Production Lead Time. Second, statistically determine the forecast error of the techniques presently being used. Finally, develop a new method of predicting PLT with greater accuracy. A data sample of 2,039 procurement actions was considered. Statistical and regression analysis was performed to obtain better forecasting models. However, it was concluded that significant forecasting error still remained.

The approach used by Wheelock will be used in this study. His assumption was to consider variables that are readily available to the decision maker. While this study will essentially use the same variables, the approach is slightly different. Where-as Wheeler took a sample of many different categories in his analysis, this report will

concentrate on a particular category of items, namely Cable Assemblies and Wiring Harnesses.

By confining the analysis to a single category, it is assumed that the general variability of lead time can be greatly reduced for that category, as opposed to a conglomeration of multicategories. It is assumed that this action will bring about a significant reduction in forecasting error. This type of analysis can then be extended to encompass each of the seventeen groups and categories.

A visit to Redstone Arsenal in Huntsville, Alabama was undertaken to review current procedures in the Production and Procurement Office. This review provided additional background information on the problems of inadequate estimates of PLT.

In the next chapter, the regression model employed in this investigation will be discussed.

CHAPTER III

THE REGRESSION MODEL

Selection of the Model

Regression modeling is one of the decision maker's most powerful tools. Regression modeling is simply determining the best mathematical model to fit a set of data observations, while minimizing the error of prediction in a least squares sense. The actual theory involved in arriving at and determining which models to use will not be discussed in this paper. However, if the reader is a little rusty in his knowledge or understanding of regression analysis, there are several fine reference texts available which cover the subject thoroughly. These are listed in the List of References at the end of this report as numbers (1), (4), (5), and (6).

The easiest and probably the most commonly used regression models are Multiple Linear First Order models. These models are of the form shown in Equation (3.1) where

$$(3.1) \quad Y = b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n + \epsilon$$

In Equation (3.1), Y denotes the dependent variable. This is the variable which will be estimated by the right hand side of Equation (3.1). The X variables are denoted as

independent variables. These are the variables which will be used to estimate the dependent variable Y. The b's in Equation (3.1) are the regression coefficients. The regression coefficients are obtained by solving the n independent regression equations, where n equals the number of data observations. ϵ is the difference between the observed value of Y and its predicted value. ϵ is commonly known as the residual error. It is desired to make this residual error as small as possible in order to obtain the best prediction model.

The regression model used during this investigation is shown in Equation (3.2) where

$$\text{(3.2)} \quad PLT = b_0 + (b_1)(UNIT) + (b_2)(QUAN) + (b_3)(COST) + \epsilon$$

PLT is the Actual Production Lead Time of each contract, UNIT is the unit purchase price per item, QUAN is the quantity of purchase, and COST is the total contract price. Independent variables UNIT, QUAN and COST were chosen because they are the most readily available variables to the decision maker.

The solution of the regression coefficients is straightforward but very tedious as more variables are considered. However, there are many "canned" computer programs available to perform the regression analysis efficiently and at moderate cost. One such program is

IBM's Statistical Analysis System (SAS) which was employed in this investigation. The next section of this chapter will describe the SAS computer program.

Statistical Analysis System Computer Program

SAS is an extremely simple and versatile program which requires a bare minimum of keypunching and card inputing. With a little practice the user can master the techniques employed by SAS to gather a large amount of statistical information on the data under analysis.

The programming of SAS is similar to COBOL programming where certain key words and phrases are specified to attain desired results. SAS can output almost any type of information which the user desires, and can perform a variety of statistical tests on the regression data.

SAS can handle from 1 to 255 uniquely defined variables, and the number of observations per variable is unlimited. In addition, the data and variables can be operated on by the usual Fortran operators through Fortran Statements.

The core of the SAS program is a set of Procedures Statements. The user simply specifies which Procedures are to be employed, along with key information required by those Procedures, and SAS does the rest.

For a thorough description of the capabilities of SAS, the SAS User's Guide (2) should be consulted.

The next chapter of this report presents a detailed analysis of the regression data with the utilization of the SAS computer program.

CHAPTER IV

PROCEDURES AND RESULTS

The Data

The data used in this analysis was supplied by personnel of Redstone Arsenal, located in Huntsville, Alabama. Data from a total of thirty contracts was obtained. This data was acquired in two ways. After selecting the contracts to be studied in a random manner, the actual contracts were pulled from the Contract Files by an employee of Redstone Arsenal. The data of interest was found and summarized on a specially prepared data sheet. This method accounted for twelve of the thirty contracts.

Gathering data in this fashion proved to be a very tedious and time consuming affair. The reason for this being that the employee had to sift through many lengthy contracts, often up to a foot in depth. This method of gathering data was soon abandoned in favor of a computer printout of the Procurement History Files.

While this method expedited the gathering of data tremendously, it did not provide as much information as the previous method. As a result some of the variables that were initially considered for analysis had to be dropped due to insufficient information. The variables

that were discarded are further discussed in the Recommendations section of Chapter V. Data for the remaining eighteen contracts was acquired through this second method.

The data that was finally obtained is shown in Table 2. Included in this data is the Federal Stock Number of the item, the Vendor Code which designates the contractor of the job, and the values of the variables used in this investigation.

The Analysis of the Data

A simple computer program was run on the data of Table 2 to obtain a frequency distribution of each variable considered. Variables UNIT, QUAN, and COST displayed distributions that were approximately Normal. On the basis of the Central Limit Theorem, it is assumed that these variables would become Normally distributed as more data points are considered.

Variable PLT on the other hand displayed a distribution that approximated the Beta Distribution. This is not unusual because the Beta Distribution is commonly used to estimate project completion times in PERT and CPM networks. There will always be some minimum lead time for any contract, whether one unit or thousands of units are being produced. This time is needed by the contractor to perform the necessary administrative paper work, plan

Table 2 Data Used in the Investigation.

FEDERAL STOCK NUMBER	VENDOR CODE	UNIT (Dollars)	QUAN (Units)	COST (Dollars)	PLT (Days)
14300156179	29056	71.00	22	1562.	137
14207299474	27789	13.00	87	1131.	120
14300122868	33426	165.00	10	1650.	159
14206790795	33426	10.25	65	666.	56
14205790795	33420	7.50	121	908.	190
14300187614	26530	127.00	9	1143.	173
14305649933	30442	87.50	17	1488.	115
14305650301	1G756	98.50	25	2450.	130
14301416020	82878	85.00	26	2210.	337
14305650327	30442	79.00	22	1738.	216
14208092624	04776	20.25	491	9943.	556
14300101407	0E801	30.25	60	1815.	328
13363370486	4H614	6.90	593	4096.	183
14300156179	04776	51.15	60	3069.	218
14208092624	8C865	34.65	323	11192.	403
14301756320	9E195	25.20	90	2268.	105
14300101407	49956	112.79	22	2481.	289
14300122868	04776	60.90	29	1766.	268
14305650327	30422	77.00	32	2464.	423
14303372570	14925	8.95	133	1190.	69
14305649845	82878	36.48	109	3976.	240
14300622451	1F402	36.10	60	2166.	218
14305650301	19605	105.00	27	2835.	214
14305650327	52196	82.75	40	3310.	262
13363370486	50738	7.80	274	2137.	180
12857306717	26530	22.90	40	916.	73
14208092624	3K423	39.60	430	17028.	136
14305735631	44626	85.00	19	1615.	212
13363370486	4H614	6.90	443	3040.	149
14305640365	30442	77.00	24	1848.	153

production schedules, and order and receive raw materials for the job.

The frequency distributions of each variable are shown in Figures 2 through 5. Also printed on each graph of Figures 2 through 5 are the summary statistics for that particular variable. Note that the interval size can be obtained by subtracting the minimum value from the maximum value, and dividing by the number of class intervals.

The SAS computer program was next used to plot each of the independent variables versus dependent variable PLT. The results are shown in Figures 6 through 8.

Figure 6 shows the scatter diagram of variables UNIT versus PLT. As can be seen from the diagram, no trends appear to exist. The points are widely dispersed, and PLT possesses a large variability.

Figure 7 is a scatter diagram of variables QUAN versus PLT. Here again the great variability of PLT is noted, and most of the data falls into the quantity range between 20 and 180.

Figure 8 depicts the COST versus PLT plot. Here it is seen that a trend does appear to exist. As the total contract cost is increased, PLT also increases. However, large PLT variability still exists.

```
FREQUENCY    2   14   11    2    1
---------------------------------------
   14             *
   13             *
   12             *
   11             *    *
   10             *    *
    9             *    *
    8             *    *
    7             *    *
    6             *    *
    5             *    *
    4             *    *
    3             *    *
    2        *    *    *    *
    1        *    *    *    *    *
---------------------------------------

INTERVAL     1    2    3    4    5
 CLASS
```

DATA OBSERVATIONS	30.000	MEAN	55.710
TOTAL	1671.000	STANDARD DEVIATION	41.756
MINIMUM	6.900	MEDIAN	45.375
MAXIMUM	165.000	SKEWNESS	0.721
RANGE	158.100	KURTOSIS	0.840

Figure 2 Frequency Distribution and Summary Stati[illegible]
for Variable UNIT.

```
FREQUENCY    6   8   5   3   2   0   0   0   1   0   1   0   0   2   0   1     1
----------------------------------------------------------------------------  -------
    8            *
    7            *
    6        *   *
    5        *   *   *
    4        *   *   *
    3        *   *   *   *
    2        *   *   *   *   *                                   *
    1        *   *   *   *   *               *       *           *       *     *
----------------------------------------------------------------------------  -------
INTERVAL     1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16    19
 CLASS
```

DATA OBSERVATIONS	30.000	MEAN	123.433
TOTAL	3703.433	STANDARD DEVIATION	164.114
MINIMUM	9.000	MEDIAN	50.000
MAXIMUM	593.000	SKEWNESS	1.705
RANGE	584.000	KURTOSIS	1.556

Figure 3 Frequency Distribution and Summary Statistics for Variable QUAN.

```
FREQUENCY    0   7  13   5   2   0   0   0   0   0   0   1   1   0     0   1
---------------------------------------------------------------------   --------
      13            *
      12            *
      11            *
      10            *
       9            *
       8            *
       7        *   *
       6        *   *
       5        *   *   *
       4        *   *   *
       3        *   *   *
       2        *   *   *   *
       1        *   *   *   *                           *   *               *
---------------------------------------------------------------------   --------
INTERVAL     1   2   3   4   5   6   7   8   9  10  11  12  13  14    19  20
 CLASS
```

DATA OBSERVATIONS	30.000	MEAN	3136.700
TOTAL	94101.015	STANDARD DEVIATION	3501.759
MINIMUM	666.000	MEDIAN	2151.500
MAXIMIM	17028.000	SKEWNESS	2.896
RANGE	16362.000	KURTOSIS	7.855

Figure 4 Frequency Distribution and Summary Statistics for Variable COST.

```
FREQUENCY    0   3   6   7   5   3   2   1   1   1   0   0   1
------------------------------------------------------------------
     7                   *
     6               *   *
     5               *   *   *
     4               *   *   *
     3           *   *   *   *   *
     2           *   *   *   *   *   *
     1           *   *   *   *   *   *   *   *   *           *
------------------------------------------------------------------

INTERVAL     1   2   3   4   5   6   7   8   9  10  11  12  13
 CLASS
```

DATA OBSERVATIONS	30.000	MEAN	210.400
TOTAL	6312.000	STANDARD DEVIATION	112.413
MINIMUM	56.000	MEDIAN	186.500
MAXIMUM	556.000	SKEWNESS	1.392
RANGE	500.000	KURTOSIS	1.948

Figure 5 Frequency Distribution and Summary Statistics for Variable PLT.

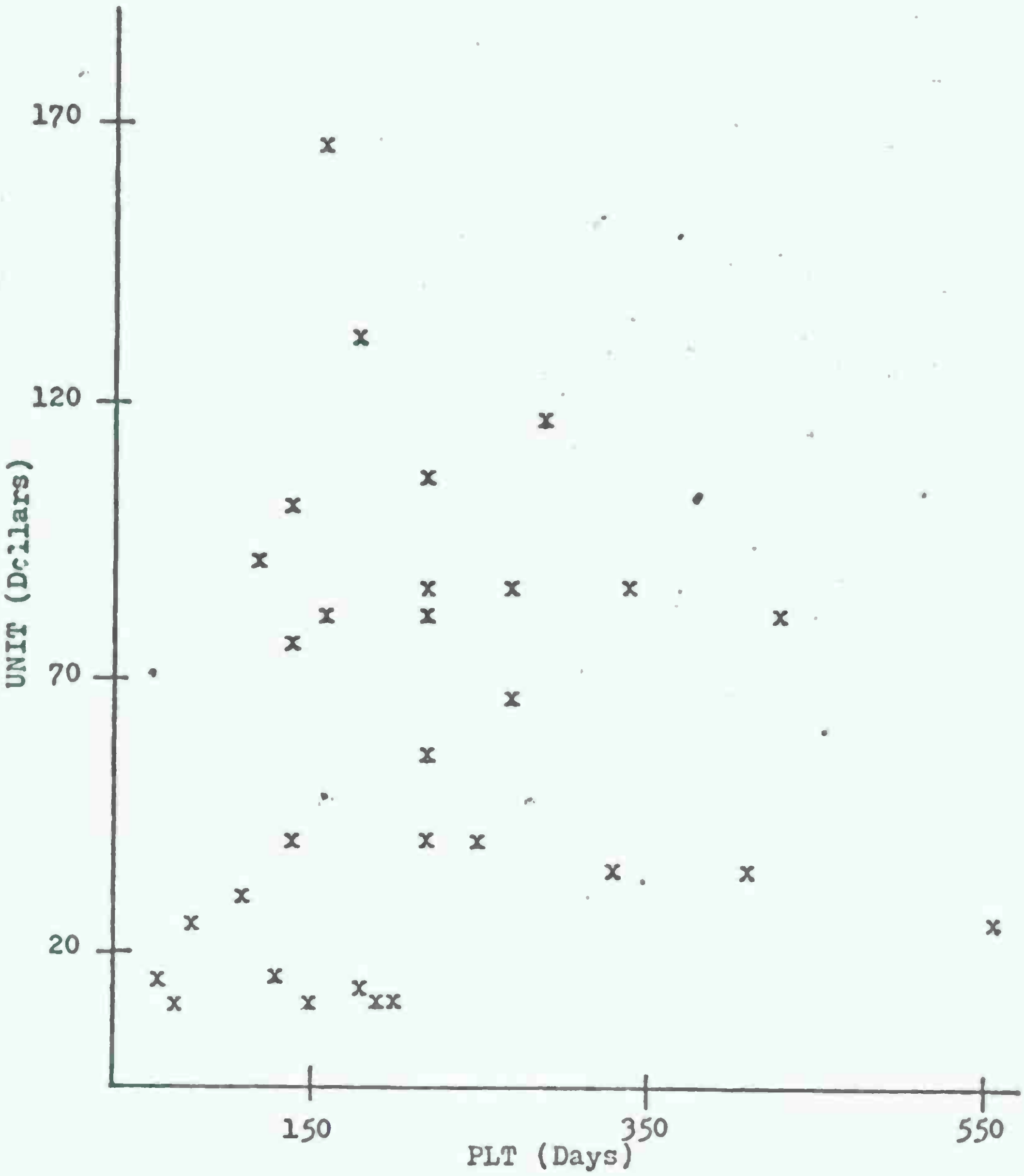

Figure 6 Scatter Plot of UNIT versus PLT.

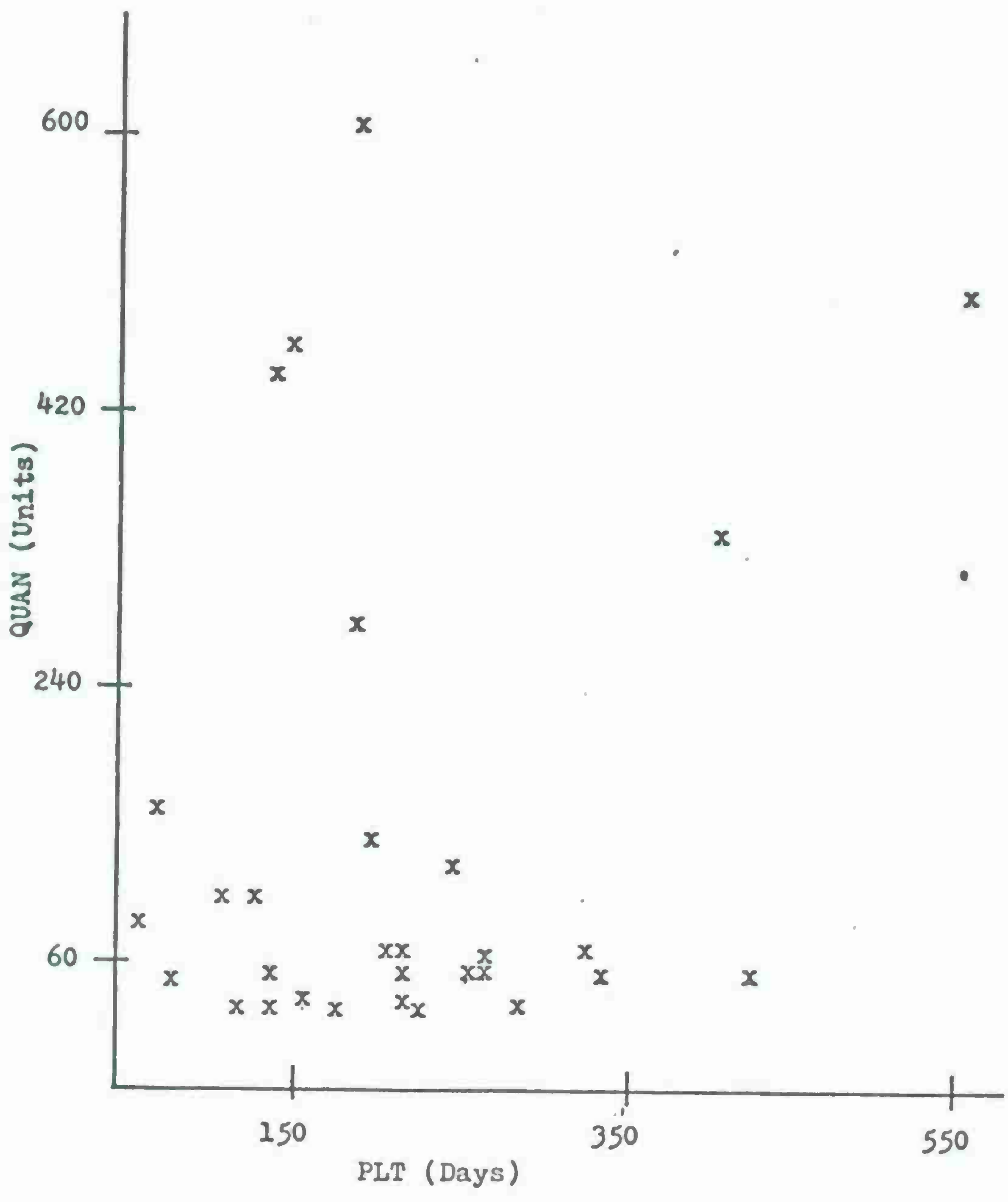

Figure 7 Scatter Plot of QUAN versus PLT.

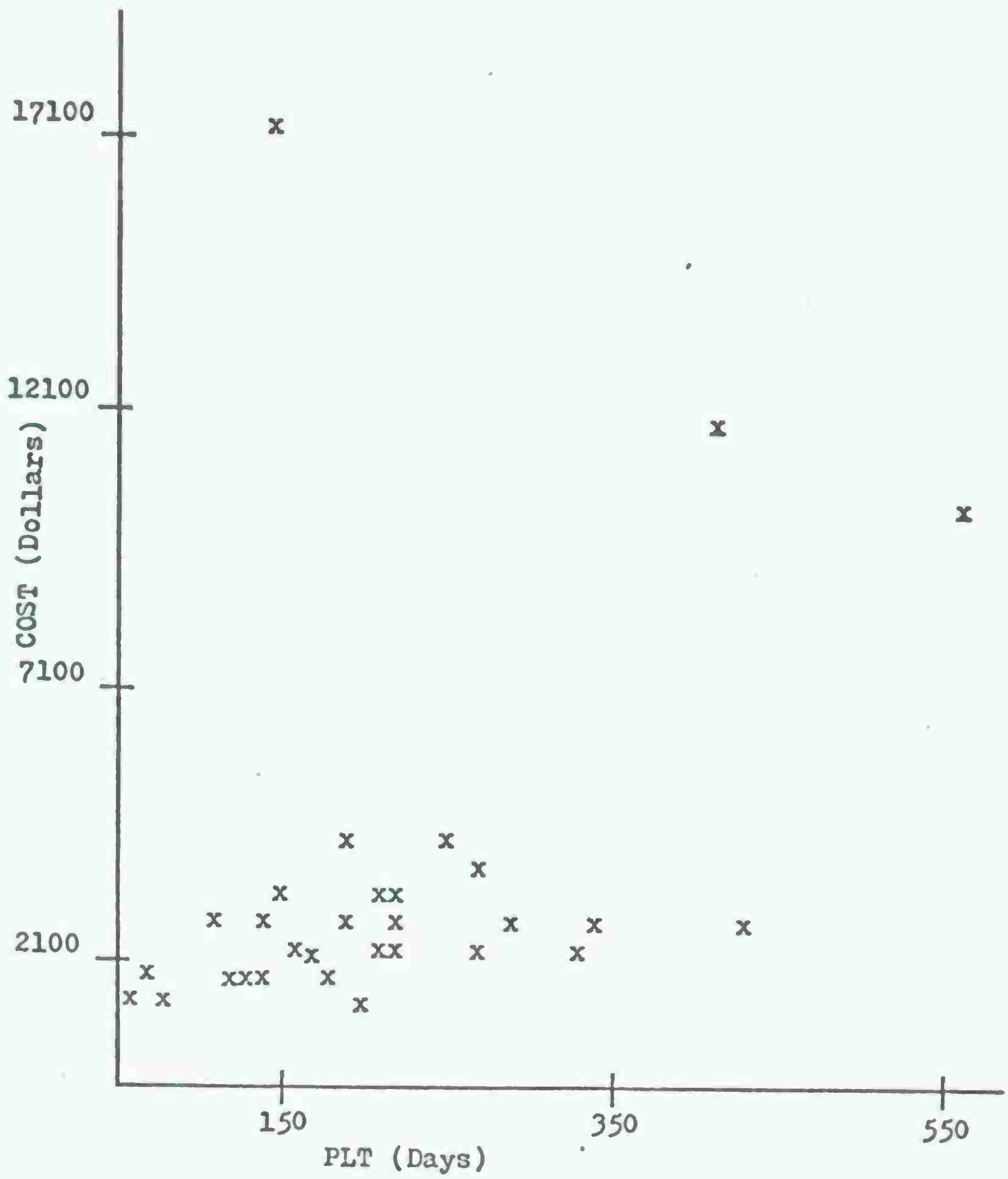

Figure 8 Scatter Plot of COST versus PLT.

After carefully studying Figures 6 through 8 it was concluded that a good mathematical model would probably not be found by regressing the data on these thirty contracts. Indeed, such was the case after doing the actual regression. A very low R^2 value and a low F ratio were encountered for the PLT model of Equation (3.2). The R^2 value is the ratio of the sum of squares due to regression divided by the total sum of squares adjusted for the mean. The significance of this value indicates whether the regression model is correct. In this case it is not. Ideally, an R^2 value between 0.90 and 1.0 is strived for. The regression coefficients and other significant statistics are summarized in Table 3 for this regression. Table 3 also lists the R^2 values for all two variable and three variable models considered.

The correlation matrix for this regression is also shown in Table 3. The correlation matrix displays how the variables are correlated with each other. A value close to 0.0 implies very little correlation, while a value close to 1.0 implies a large correlation.

Looking back to Figure 8, the scatter diagram of COST versus PLT, COST appeared to have a greater impact on PLT than the statistics displayed. It was theorized that instead of looking at the whole picture, a small part of the picture should be investigated at a time. The plan of attack was simple. The data for each independent variable

Table 3 Regression Statistics for the Model of Equation (3.2).

VARIABLES	SUM	MEAN	STD DEV
QUAN	3703.000	123.433	164.114
UNIT	1671.320	55.710	41.756
COST	94101.000	3136.700	3501.760
PLT	6312.000	210.400	112.413

ANOVA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	3	58295.731	19431.910
ERROR	26	308169.468	11852.672
TOTAL	29	366465.200	

F VALUE	PROB OF F	R-SQUARE
1.639	0.2036	0.159

SOURCE	DF	SEQUENTIAL SS	F VALUE	PROB F
QUAN	1	16493.326	1.391	0.2488
COST	1	33072.373	2.790	0.1068
UNIT	1	8730.032	0.736	0.3986

SOURCE	REGRESSION COEFFICIENTS	T FOR H_0: B = 0	PROB T
INTERCEPT	138.831	2.77544	0.0101
QUAN	0.077	0.37691	0.7093
COST	0.010	1.31480	0.2001
UNIT	0.530	0.85822	0.3986

NUMBER OF VARIABLES IN MODEL	R-SQUARE	VARIABLES IN MODEL
1	0.006	UNIT
1	0.045	QUAN
1	0.134	COST
2	0.103	QUAN UNIT
2	0.135	QUAN COST
2	0.154	UNIT COST
3	0.159	QUAN UNIT COST

Continuation of Table 3

CORRELATION MATRIX

	QUAN	UNIT	COST	PLT
QUAN	1.000	-0.564	0.647	0.212
UNIT	-0.564	1.000	-0.167	0.079
COST	0.647	-0.167	1.000	0.366
PLT	0.212	0.079	0.366	1.000

was sorted, and divided up into intervals being careful to include at least six or more data observations per interval to start with.

SAS includes procedures to sort the data by assigned levels of a dummy variable which the user may introduce. SAS can then regress the original data according to the assigned levels specified by the dummy variables. One such possible assignment of levels to the three independent variables is shown in Table 4. QUANC, COSTA, and UNITZ are the dummy variables assigned to represent the levels of QUAN, COST and UNIT respectively.

The assigned levels themselves are never actually used in any of the calculations performed by SAS. The dummy variables are simply used as a manipulating tool on the data observations. An example of how these level assignments look for dummy variable UNITZ is displayed in Table 5.

The regressions performed in this manner are summarized in Tables 6, 7, and 8. The R^2's found in Tables 6 and 7 are in many cases higher than the previous regression (Table 3), but still less than satisfactory for levels of QUANC and COSTA. However, when regressed by intervals of UNITZ. the R^2's are extremely promising, and in some cases excellent. This is shown in Table 8.

Table 4 Dummy Variable Level Assignments Based on Intervals of QUAN, COST and UNIT.

VARIABLE	DUMMY VARIABLE	LEVEL	INTERVAL SIZE
QUAN	QUANC	A	0 - 25
		B	26 - 50
		C	51 - 125
		D	126 - 600
COST	COSTA	A	0 - 1500
		B	1501 - 2000
		C	2001 - 3000
		D	3001 - 18000
UNIT	UNITZ	A	0 - 25
		B	26 - 75
		C	76 - 85
		D	86 - 165

Table 5 Data Divided Up into Levels
of Dummy Variable UNITZ.

QUAN	UNIT	COST	PLT	UNITZ
40	22.90	916	73	A
87	13.00	1131	120	A
65	10.25	666	56	A
121	7.50	908	190	A
90	25.20	2268	105	A
133	8.95	1190	69	A
274	7.80	2137	180	A
593	6.90	4096	183	A
443	6.90	3040	149	A
491	20.25	9943	556	A
22	71.00	1562	137	B
29	60.90	1766	268	B
60	30.25	1815	328	B
60	36.10	2166	218	B
60	51.15	3069	218	B
109	36.48	3976	240	B
323	34.65	11192	403	B
430	39.60	17028	136	B
19	85.00	1615	212	C
22	79.00	1738	216	C
24	77.00	1848	153	C
26	85.00	2210	337	C
32	77.00	2464	423	C
40	82.75	3310	262	C
9	127.00	1143	173	D
17	87.50	1488	115	D
10	165.00	1650	159	D
25	98.50	2450	130	D
22	112.79	2481	289	D
27	105.00	2835	214	D

Table 6 Regression Statistics by Levels of QUANC

BY LEVEL 'A'

VARIABLE	SUM	MEAN	STD DEV
QUAN	170.000	18.888	5.840
UNIT	902.790	100.310	30.230
COST	15975.000	1775.000	437.199
PLT	1584.000	176.000	54.600

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
0.589	0.6497	0.261	COST

BY LEVEL 'B'

VARIABLE	SUM	MEAN	STD DEV
QUAN	194.000	32.333	6.282
UNIT	433.550	72.258	28.043
COST	13501.000	2250.166	839.884
PLT	1577.000	262.833	117.985

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
1.342	0.4527	0.668	COST,QUAN,UNIT

BY LEVEL 'C'

VARIABLE	SUM	MEAN	STD DEV
QUAN	652.000	81.500	24.136
UNIT	209.930	26.241	15.222
COST	15999.000	1999.875	1128.091
PLT	1475.000	184.375	86.964

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
0.792	0.5592	0.372	COST

BY LEVEL 'D'

VARIABLE	SUM	MEAN	STD DEV
QUAN	2687.000	383.857	152.506
UNIT	125.050	17.864	14.030
COST	48626.000	6946.571	5892.008
PLT	1676.000	239.428	173.977

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
0.287	0.8375	0.219	COST,QUAN

Table 7 Regression Statistics by Levels of COSTA.

BY LEVEL 'A'

VARIABLE	SUM	MEAN	STD DEV
QUAN	472.000	67.428	48.764
UNIT	277.100	39.585	47.872
COST	7442.000	1063.142	261.731
PLT	796.000	113.714	52.222

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
0.770	0.5827	0.435	UNIT

BY LEVEL 'B'

VARIABLE	SUM	MEAN	STD DEV
QUAN	186.000	26.571	15.830
UNIT	568.150	81.164	41.173
COST	11994.000	1713.428	106.798
PLT	1473.000	210.428	68.927

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
2.102	0.2778	0.677	QUAN

BY LEVEL 'C'

VARIABLE	SUM	MEAN	STD DEV
QUAN	556.000	69.500	85.916
UNIT	547.390	68.423	39.906
COST	19011.000	2376.375	231.567
PLT	1896.000	237.000	107.112

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
0.347	0.7945	0.206	QUAN

BY LEVEL 'D'

VARIABLE	SUM	MEAN	STD DEV
QUAN	2489.000	311.125	214.109
UNIT	278.680	34.835	24.959
COST	55654.000	6956.750	5197.639
PLT	2147.000	268.375	143.077

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
0.063	0.976	0.045	COST

Table 8 Regression Statistics by Levels of UNITZ.

BY LEVEL 'A'

VARIABLE	SUM	MEAN	STD DEV
QUAN	2337.000	233.700	203.230
UNIT	129.650	12.965	7.110
COST	26295.000	2629.500	8834.920
PLT	1681.000	168.100	145.067

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
28.961	0.0011	0.935	COST,QUAN

BY LEVEL 'B'

VARIABLE	SUM	MEAN	STD DEV
QUAN	1093.000	136.625	153.019
UNIT	360.130	45.016	14.502
COST	42574.000	5321.750	1577.392
PLT	1948.000	243.500	90.547

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
3.339	0.1379	0.714	COST

BY LEVEL 'C'

VARIABLE	SUM	MEAN	STD DEV
QUAN	163.000	27.166	7.652
UNIT	485.750	80.958	3.769
COST	13185.000	2197.500	629.512
PLT	1603.000	262.166	97.859

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
1.097	0.4920	0.622	UNIT

BY LEVEL 'D'

VARIABLE	SUM	MEAN	STD DEV
QUAN	110.000	18.333	7.633
UNIT	696.790	115.965	27.465
COST	12047.000	2007.833	670.792
PLT	1080.000	180.000	63.642

F VALUE	PROB OF F	R-SQUARE	SIGNIFICANT VARIABLE
252.260	0.0033	0.997	COST,QUAN,UNIT

Repeated regressions were made while changing the interval sizes for each of the three dummy variables. The results did not significantly vary for levels of QUANC and COSTA. Changing the interval sizes of UNITZ did alter regression models significantly. The interval sizes listed in Table 8 gave the best overall regression models for all levels of the dummy variable UNITZ. These results are significantly better than those listed in Tables 6 and 7.

Based on the results of Table 8, scatter diagrams of COST, QUAN and UNIT were plotted versus PLT for each level of dummy variable UNITZ. These results are shown in Figures 9 through 20. It can be observed by examining these plots that significant linear trends exist especially for levels A and B of UNITZ. For level D, there does not appear to be any significant trends, yet the regression produced an excellent model. This means that PLT is not affected by one variable alone, but is a function of all the variables together.

In observing some of these scatter diagrams, it was discovered that only one or two points were significantly separated from the rest. In an attempt to explain this phenomenon, the Federal Stock Numbers (FSN) for each item were examined. All of the items had FSN's which fell into one of four series, determined by the first four digits of

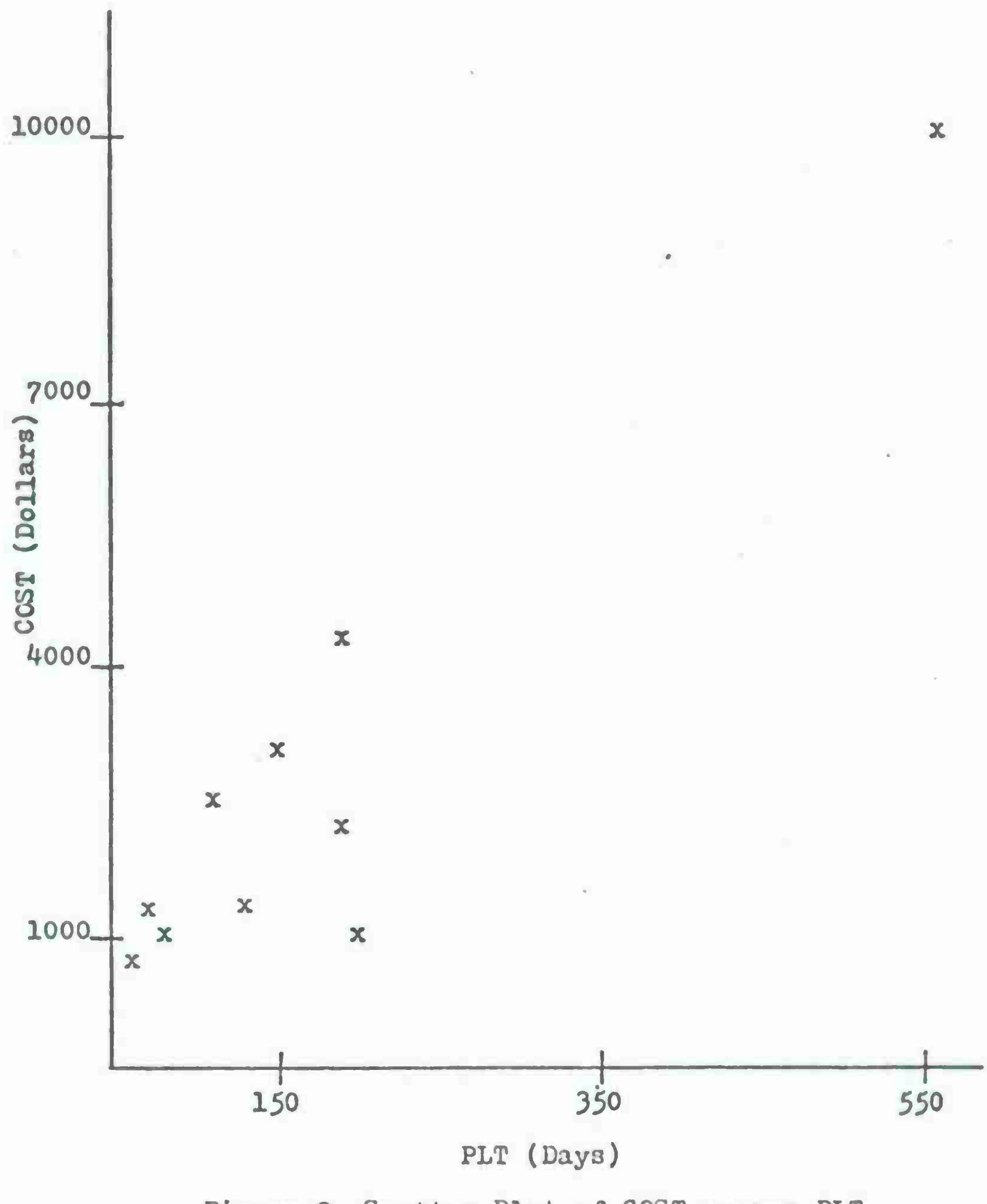

Figure 9 Scatter Plot of COST versus PLT for Level 'A' of UNITZ.

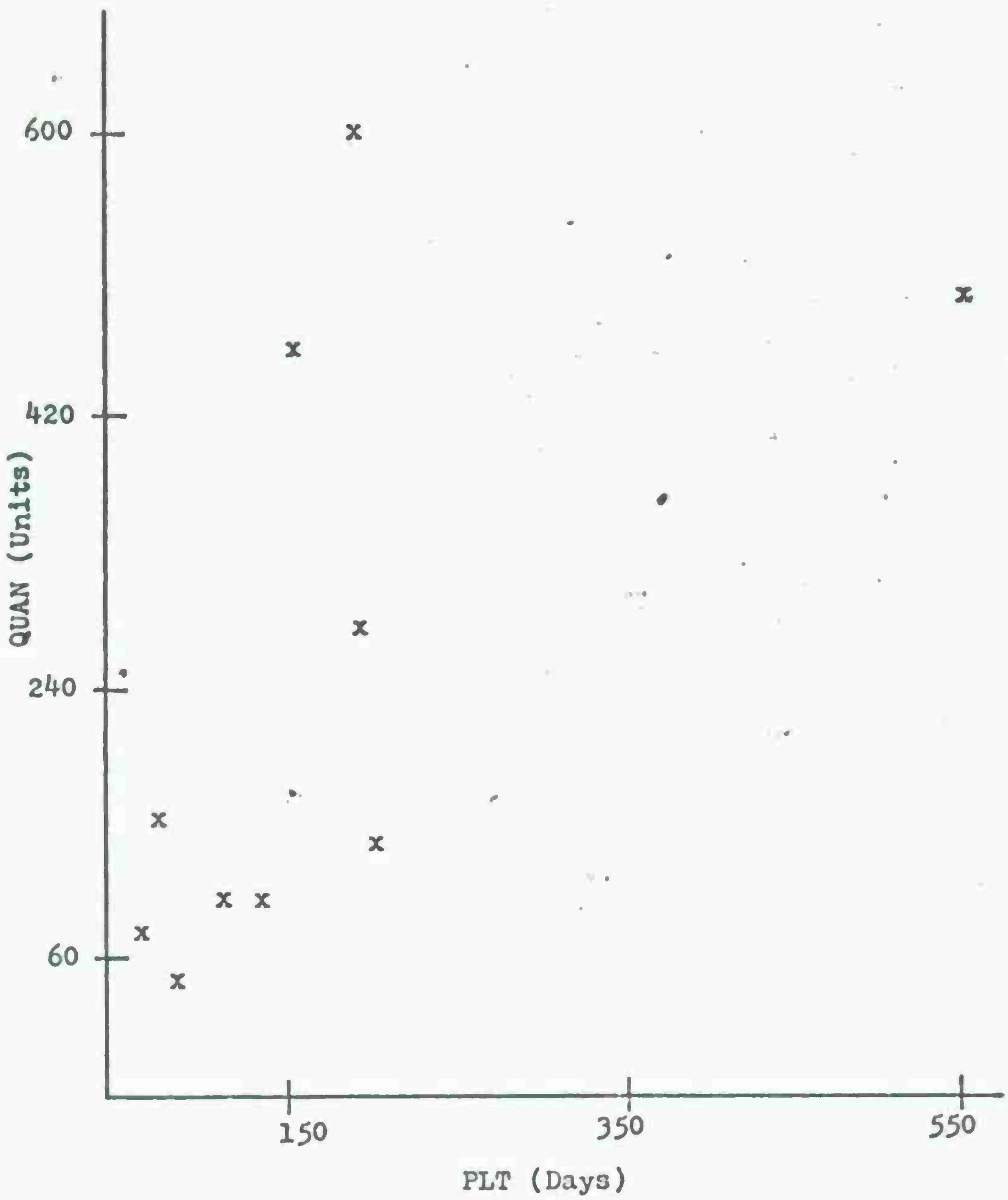

Figure 10 Scatter Plot of QUAN versus PLT for Level 'A' of UNITZ.

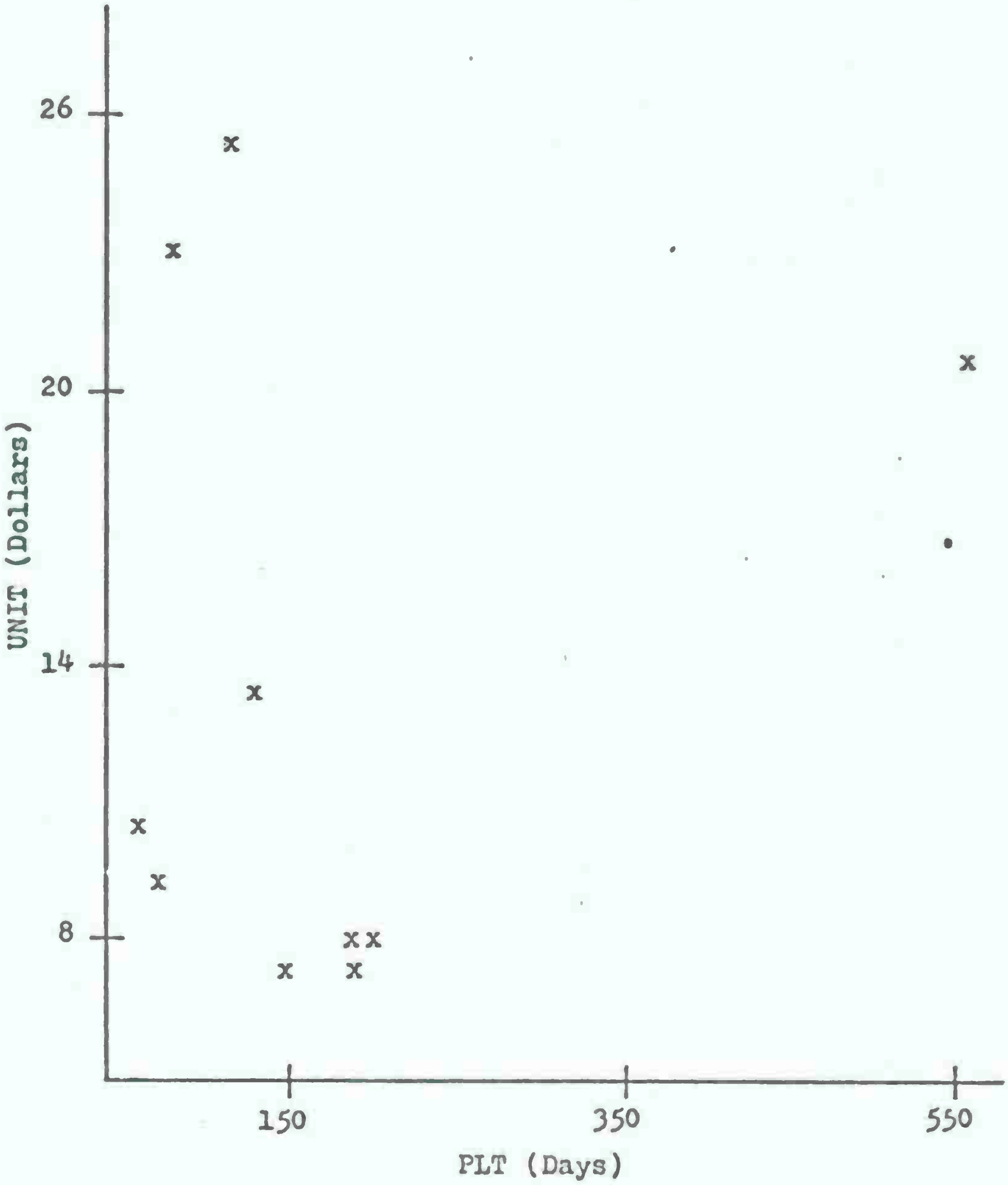

Figure 11 Scatter Plot of UNIT versus PLT for Level 'A' of UNITZ.

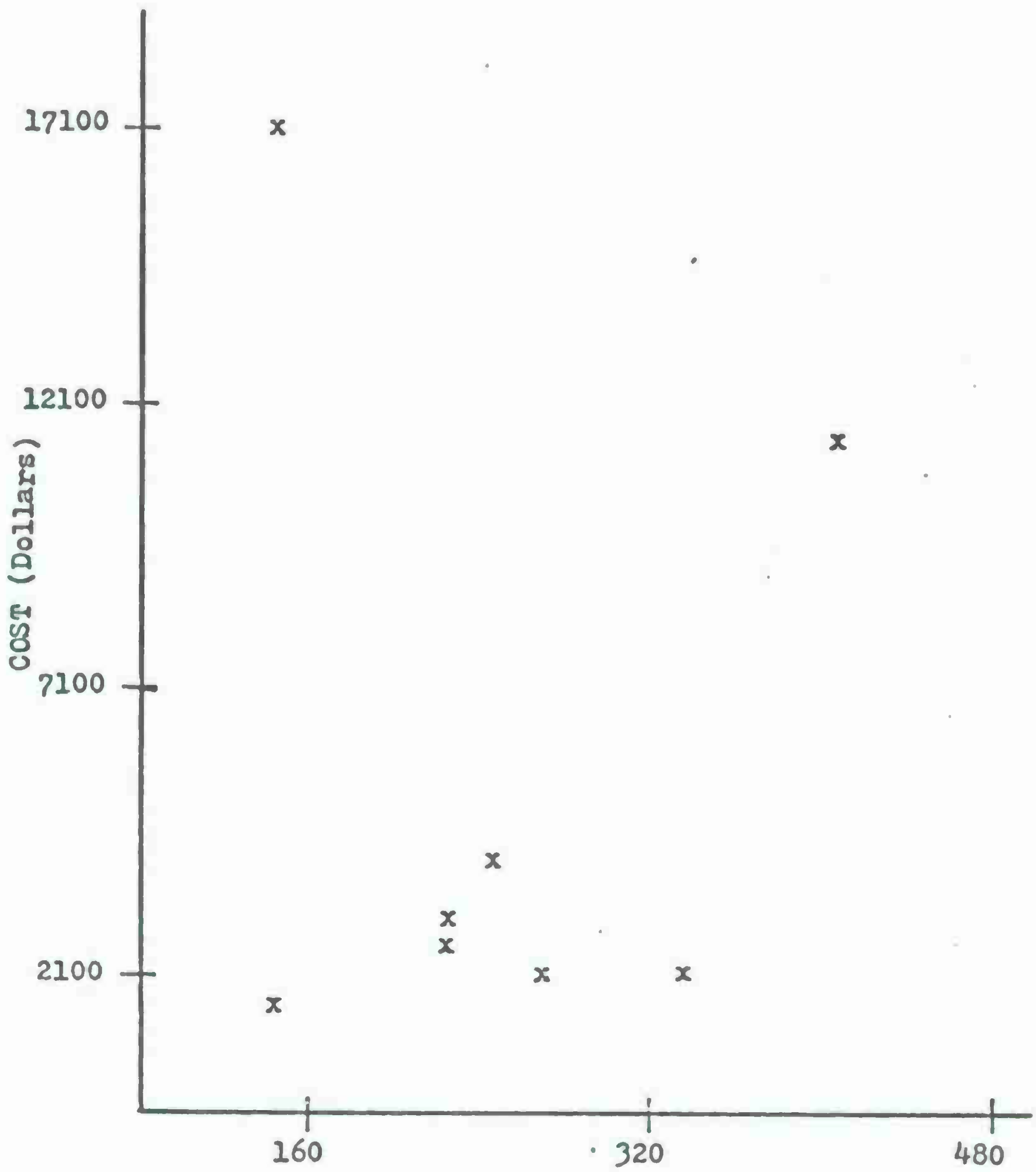

Figure 12 Scatter Plot of COST versus PLT forLevel 'B' of UNITZ.

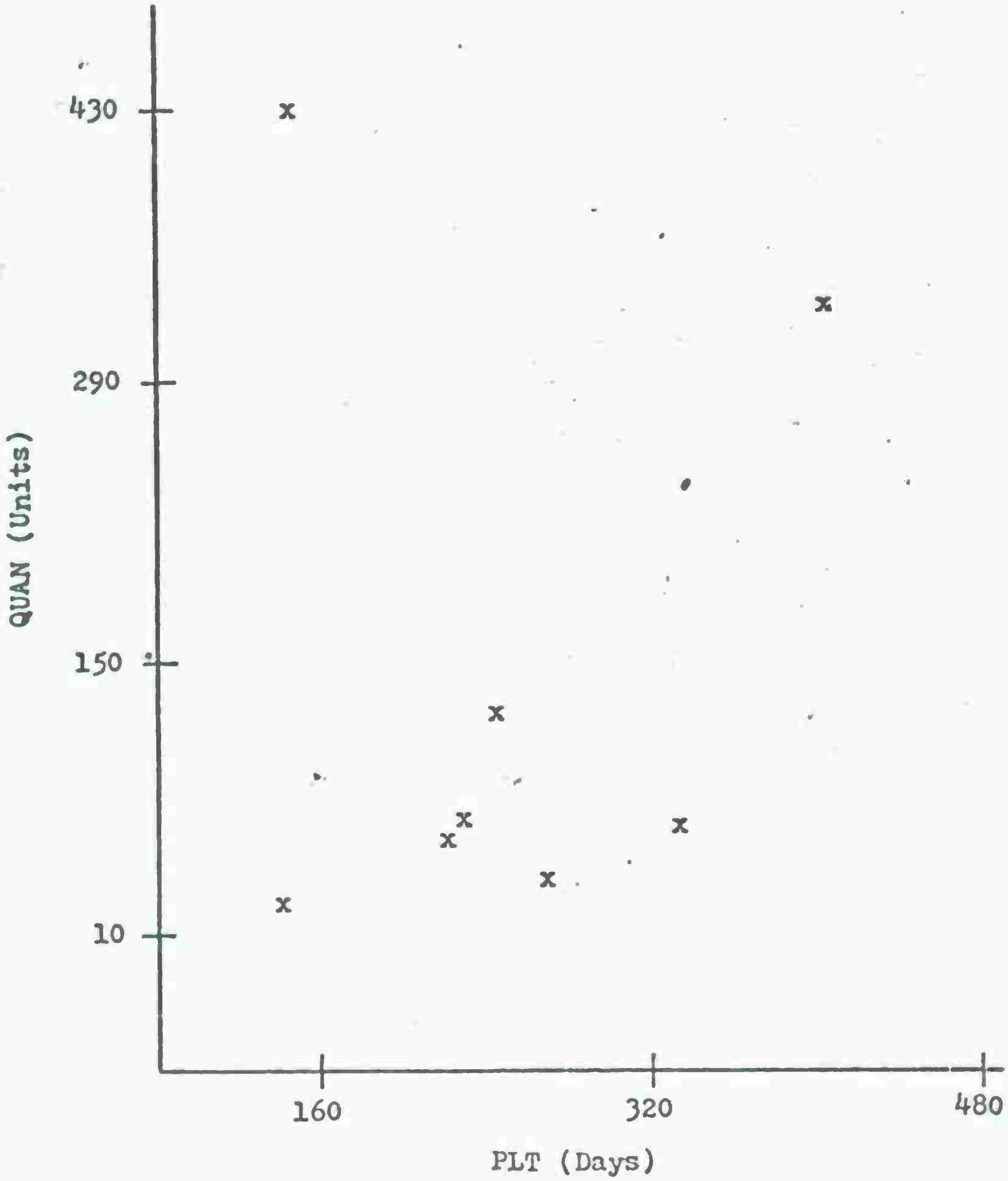

Figure 13 Scatter Plot of QUAN versus PLT for Level 'B' of UNITZ.

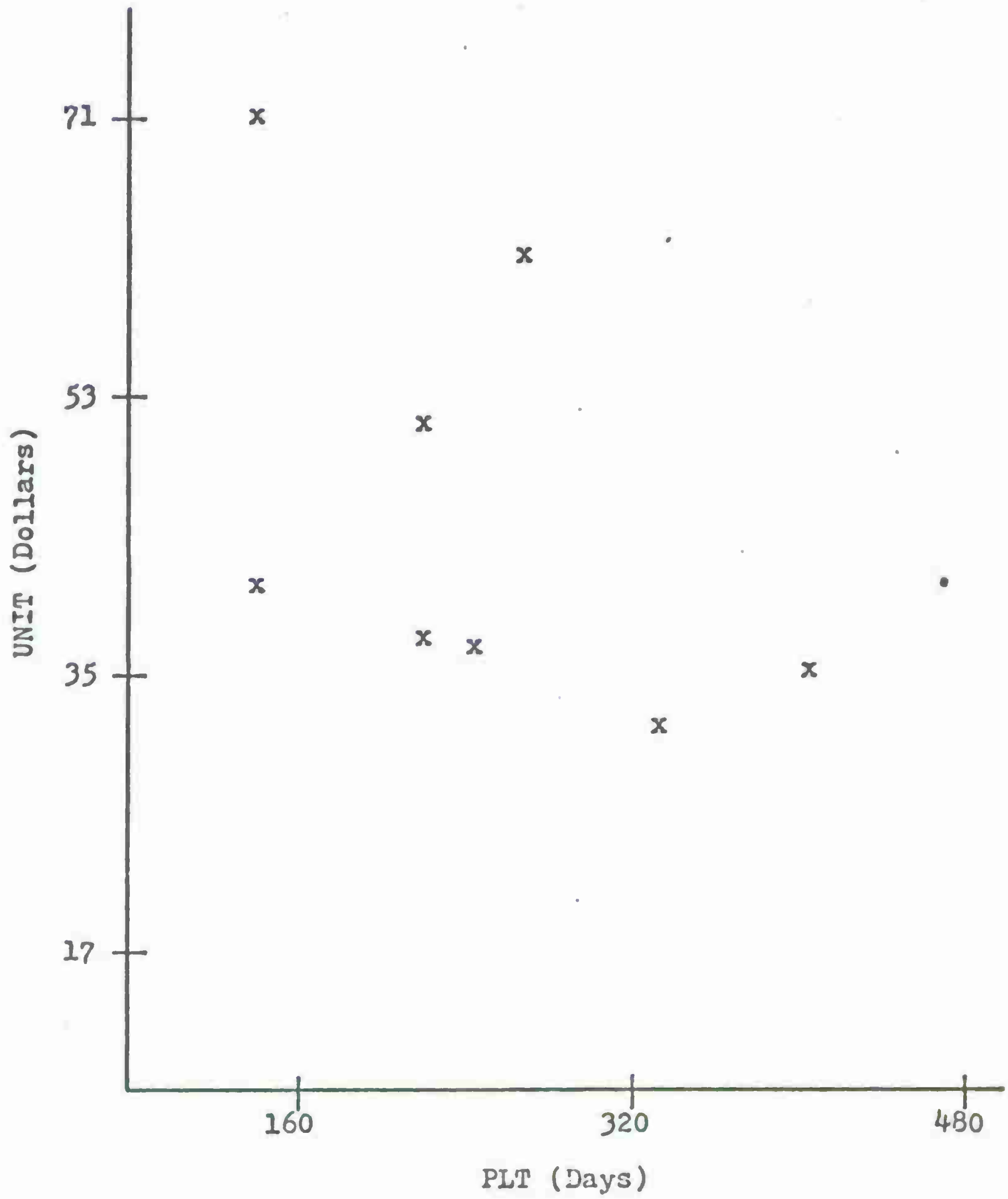

Figure 14 Scatter Plot of UNIT versus PLT for Level 'B' of UNITZ.

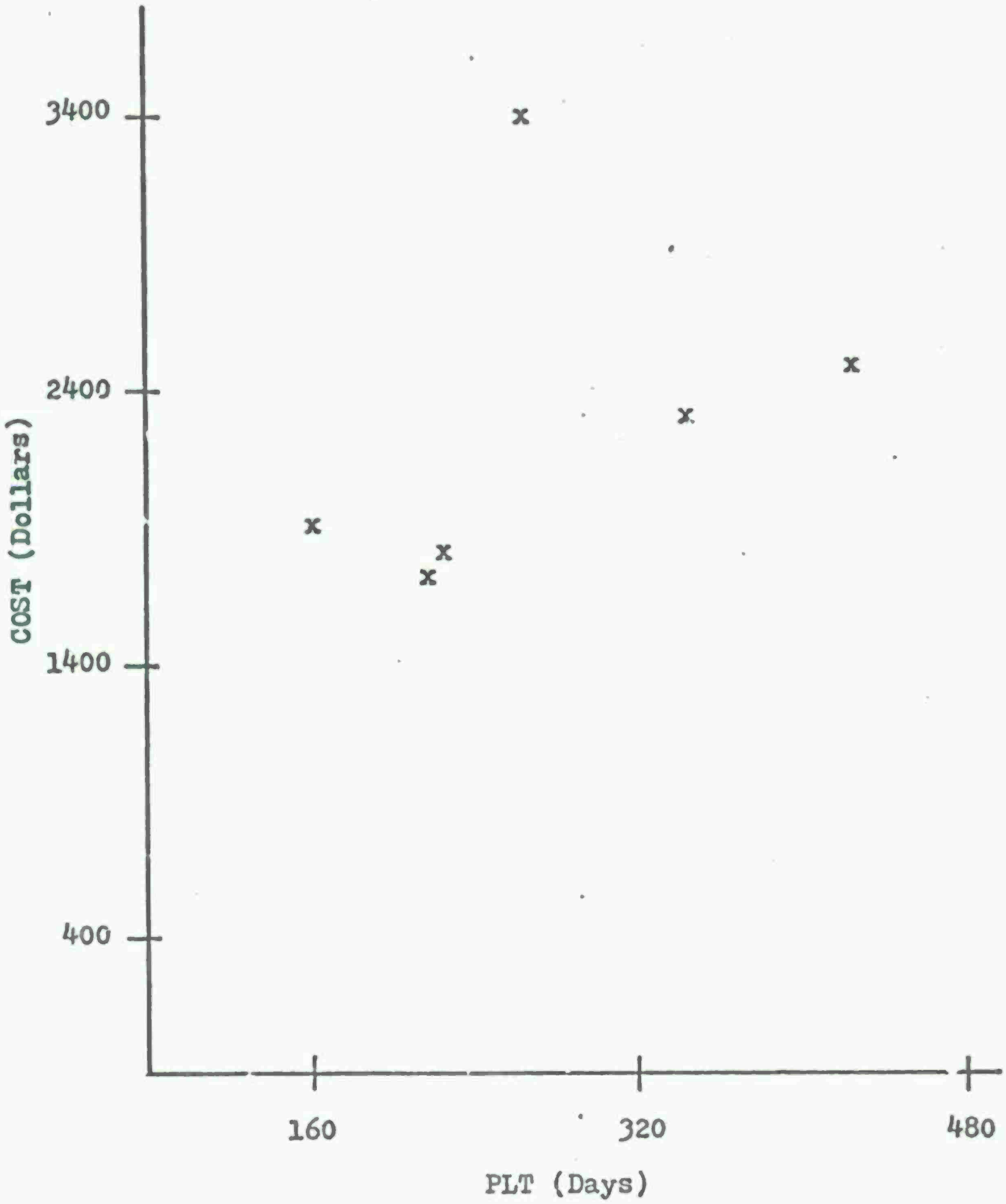

Figure 15 Scatter Plot of COST versus PLT for Level 'C' of UNITZ.

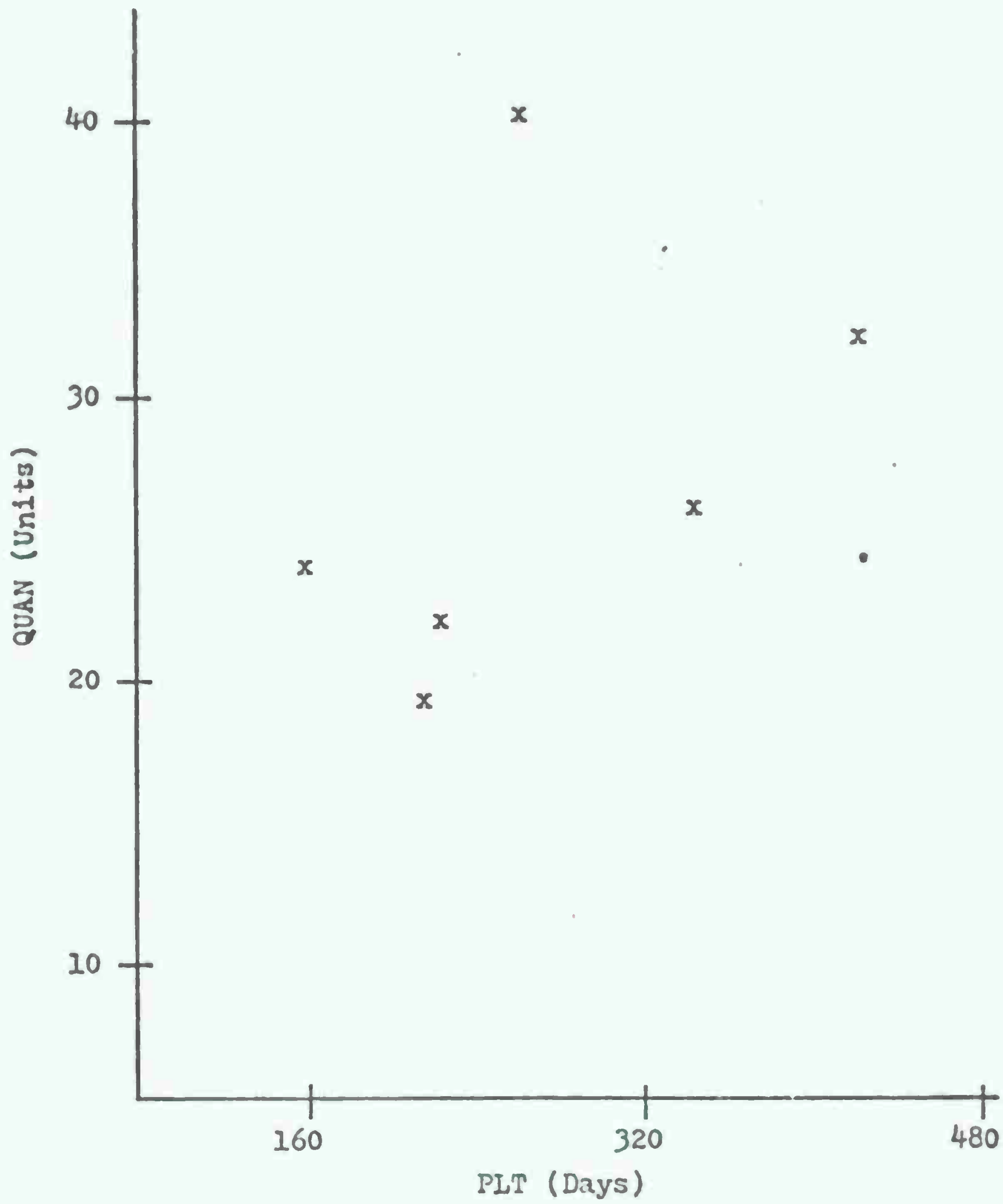

Figure 16 Scatter Plot of QUAN versus PLT for Level 'C' of UNITZ.

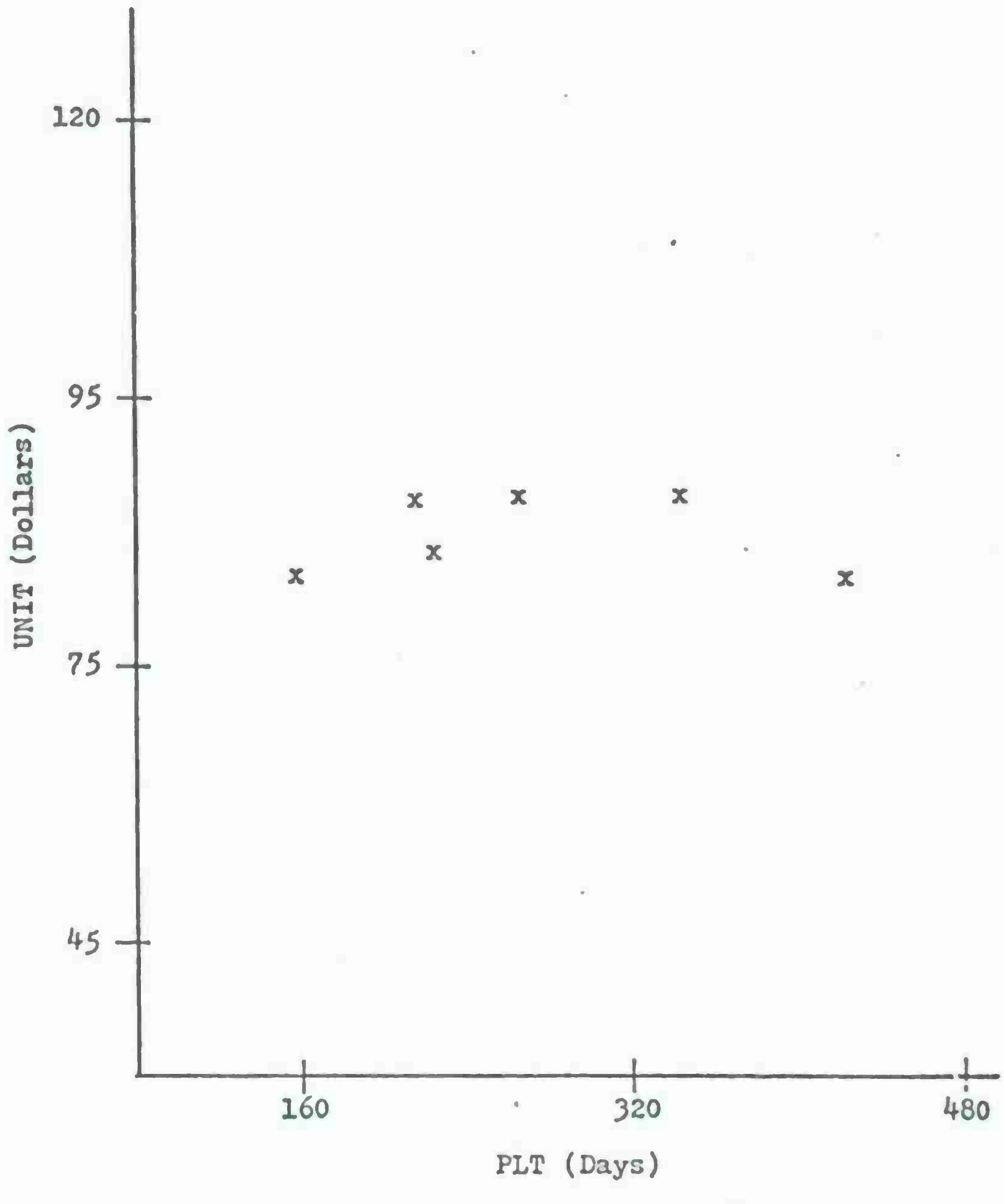

Figure 17 Scatter Plot of UNIT versus PLT for Level 'C' of UNITZ.

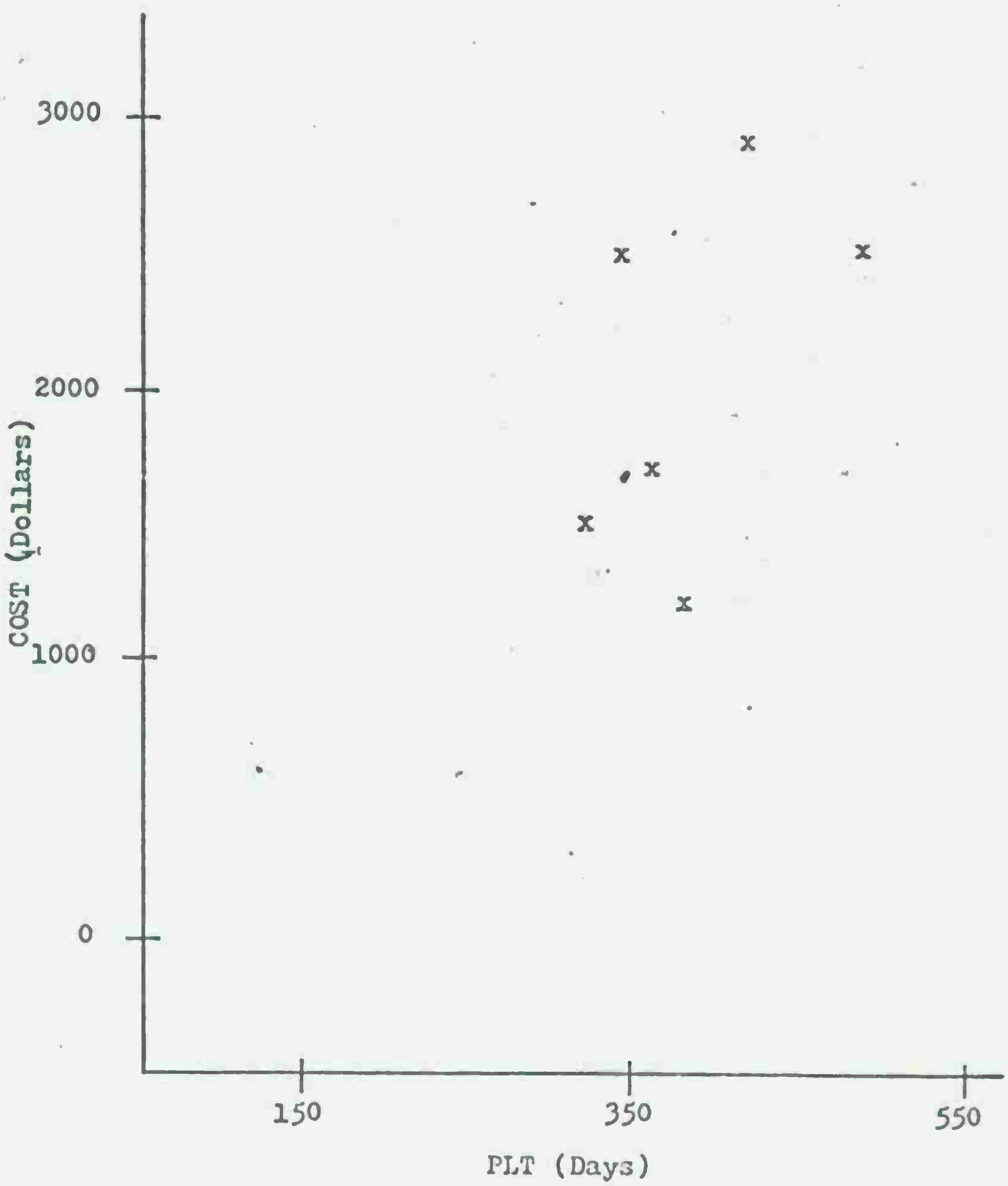

Figure 18 Scatter Plot of COST versus PLT for Level 'D' of UNITZ.

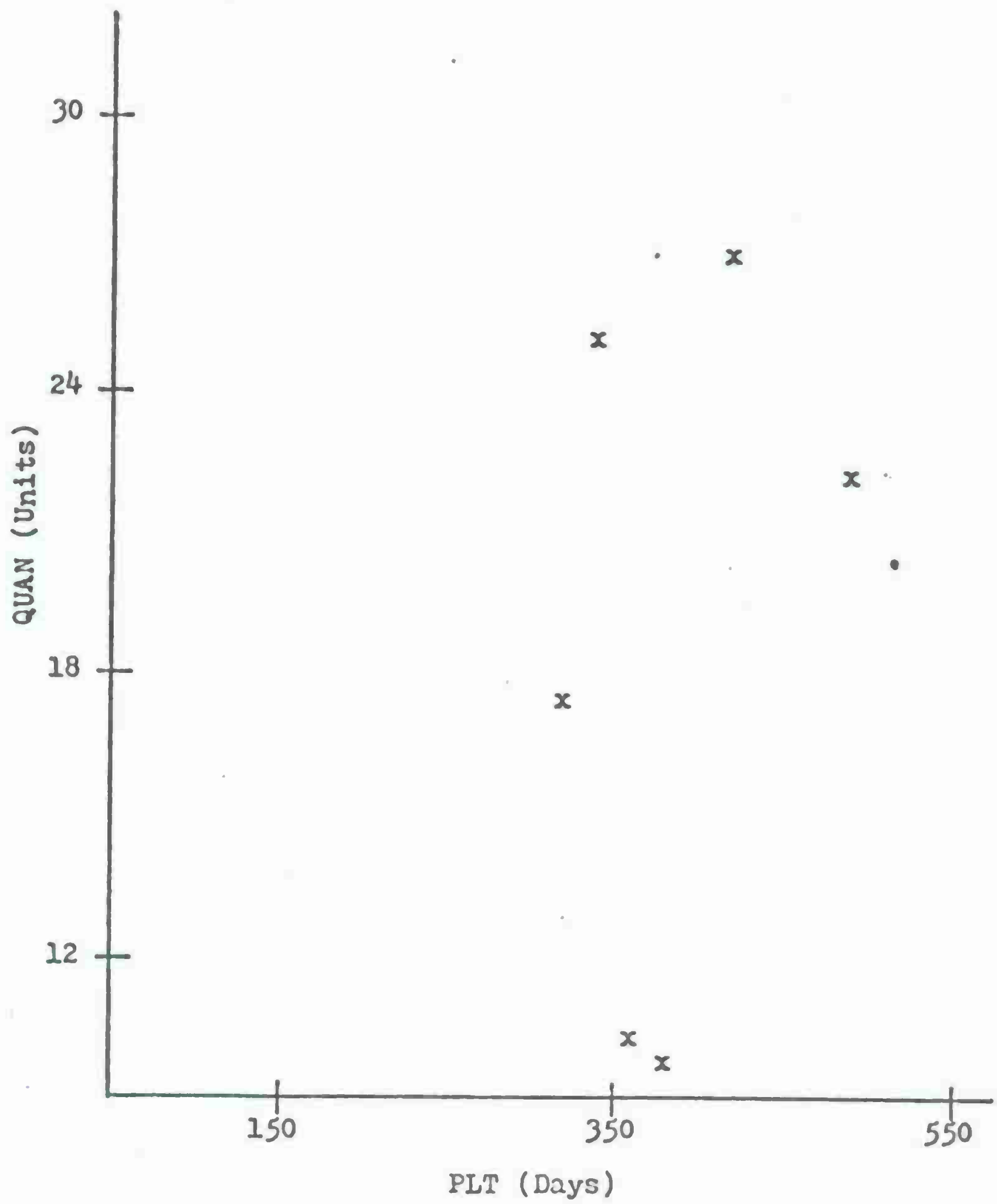

Figure 19 Scatter Plot of QUAN versus PLT for Level 'D' of UNITZ.

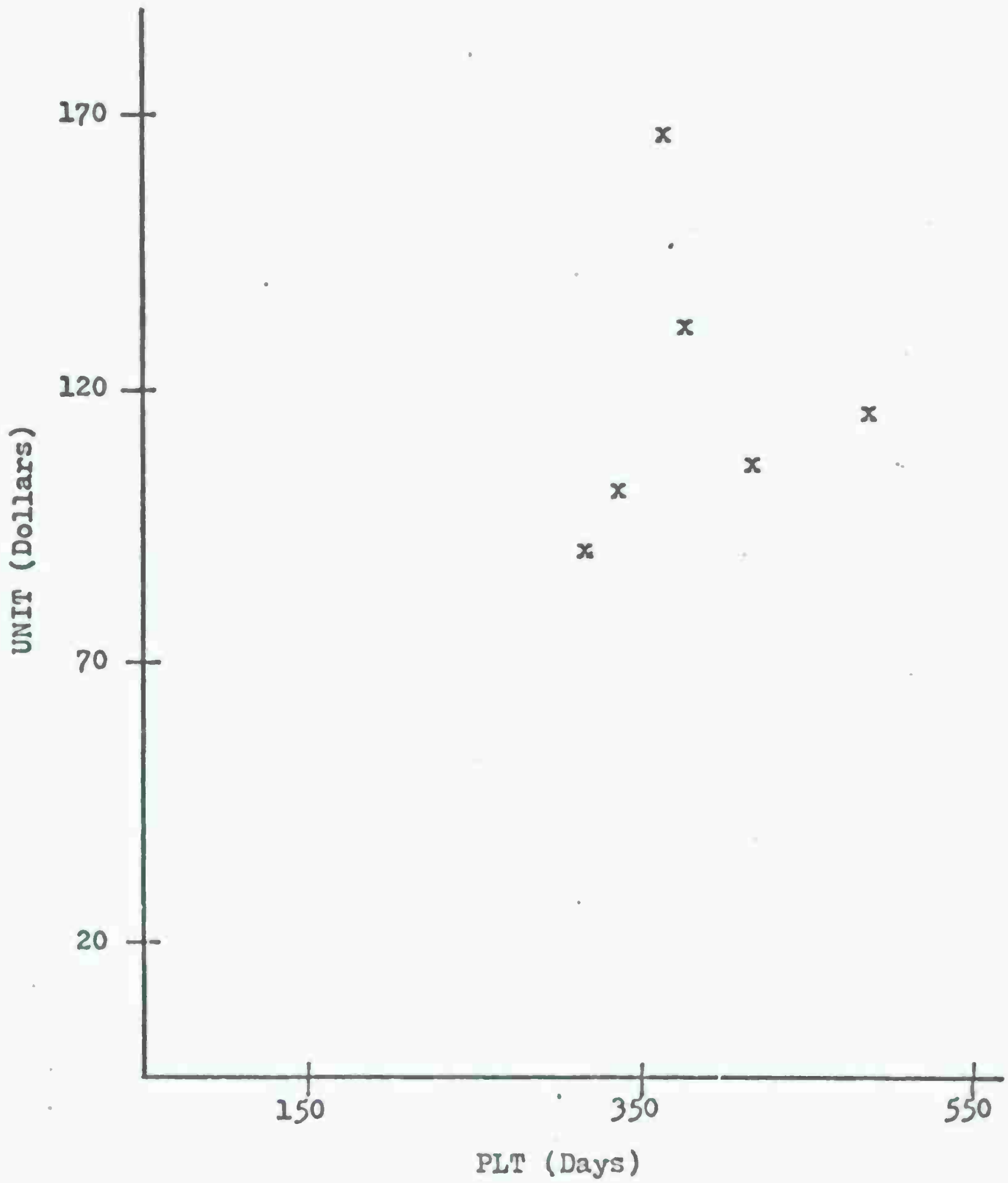

Figure 20 Scatter Plot of UNIT versus PLT for Level 'D' of UNITZ.

the eleven digit FSN. These four series and their classifications are:

1285 Series - Fire Control Radar Equipment
1336 Series - Guided Missle Warheads and Explosive Components
1420 Series - Guided Missle Components
1430 Series - Guided Missle Remote Control Systems

The majority of the items fell into the 1430 Series. Figures 21 through 26 are the scatter diagrams of Figures 9 through 14 redrawn to differentiate each data point according to FSN series. Figures 15 through 20 are not redrawn because they all exhibit the 1430 Series stock number. As can be witnessed from Figures 21 through 26, possible trends among items with similar FSN's may exist. However, due to the small amount of data points analyzed, nothing conclusive could be determined.

Table 9 lists the regression coefficients that were obtained for the various levels of UNITZ. Table 10 lists the actual versus predicted PLT's along with the upper and lower 95 percent confidence limits.

Chapter V will now present a discussion of the conclusions drawn from this investigation, and the recommendations for further action.

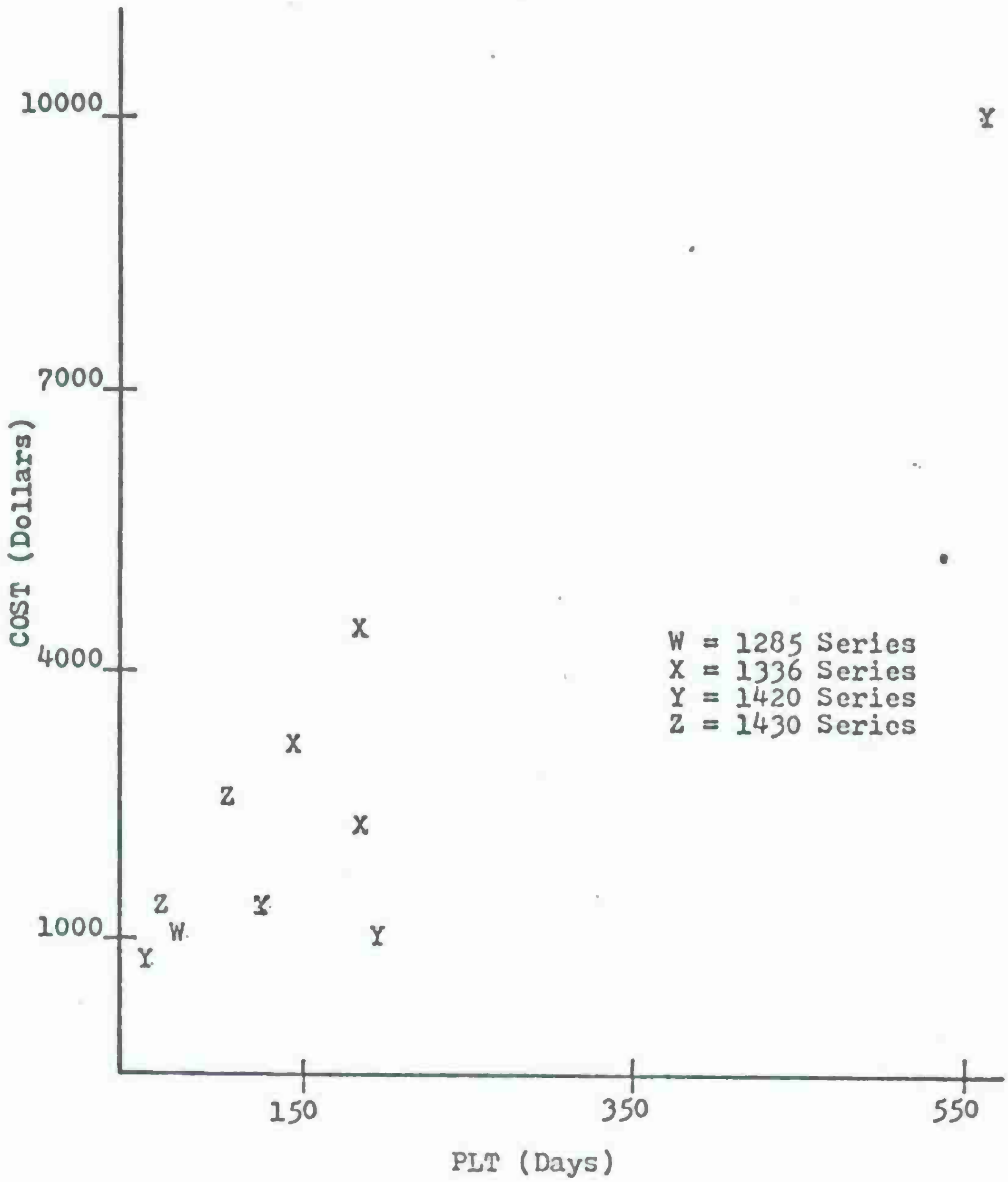

Figure 21 Scatter Plot of COST versus PLT for Level 'A' of UNITZ, Differentiated According to Federal Stock Number Series.

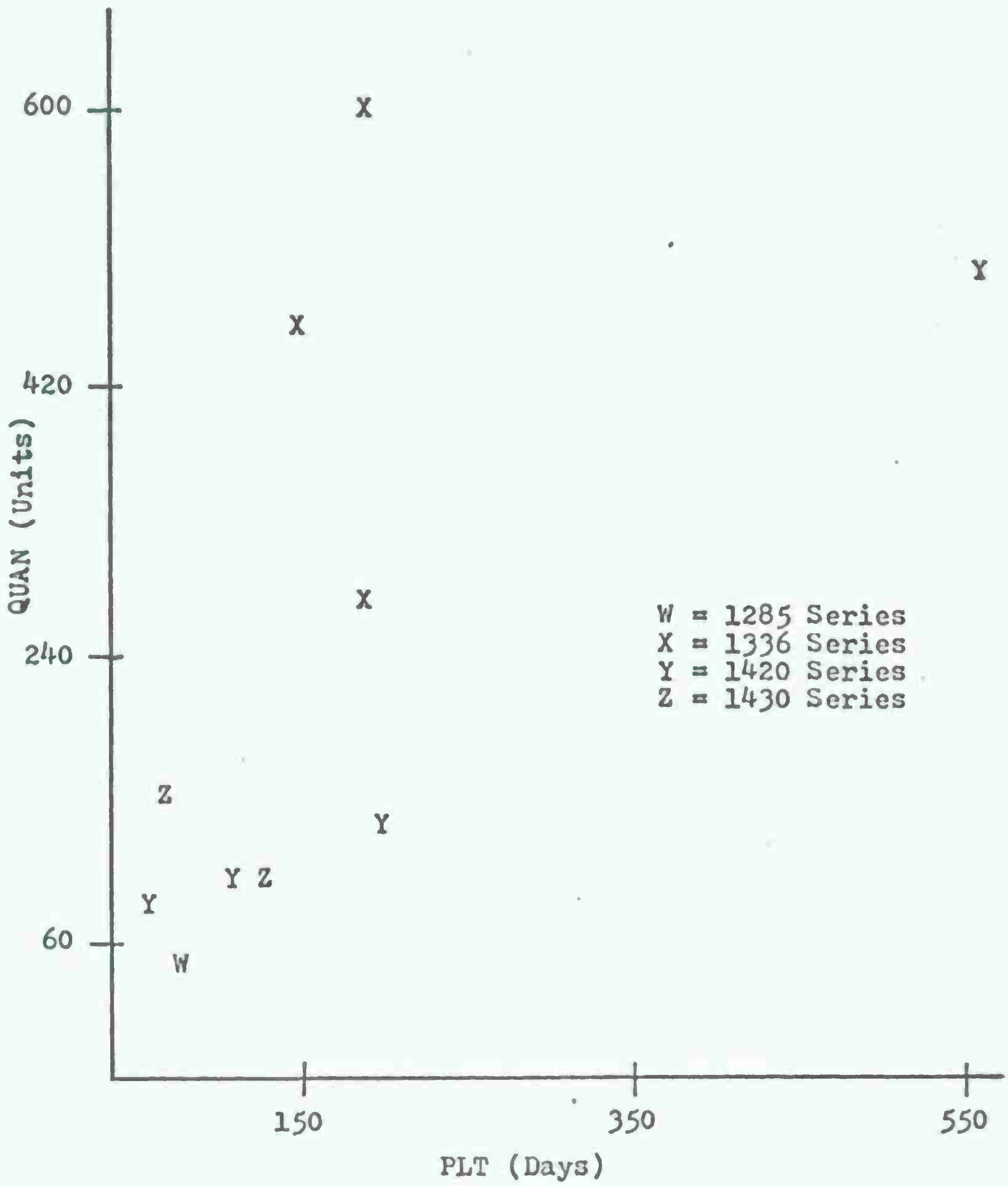

Figure 22 Scatter Plot of QUAN versus PLT for Level 'A' of UNITZ, Differentiated According to Federal Stock Number Series.

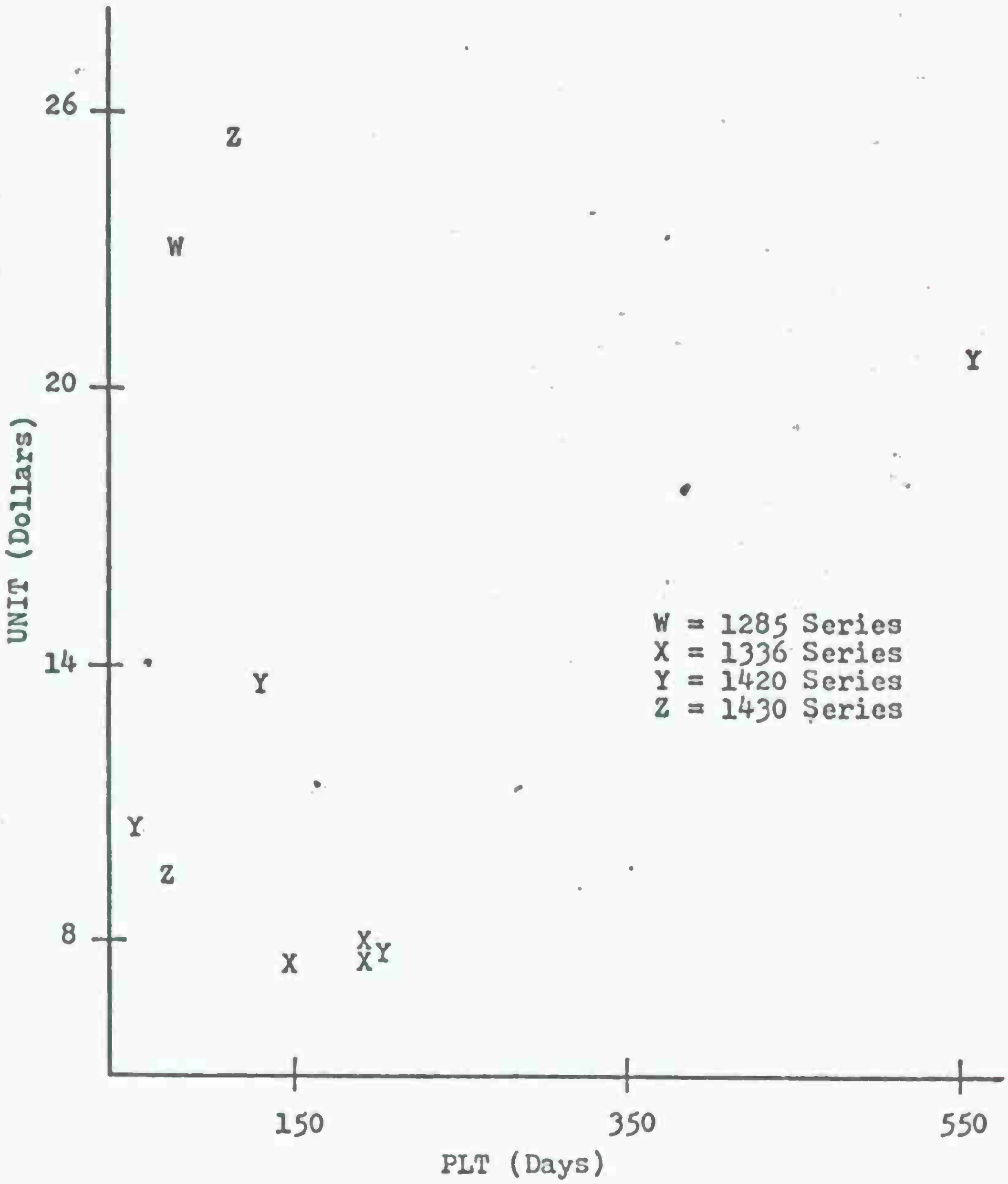

Figure 23 Scatter Plot of UNIT versus PLT for Level 'A' of UNITZ, Differentiated According to Federal Stock Number Series.

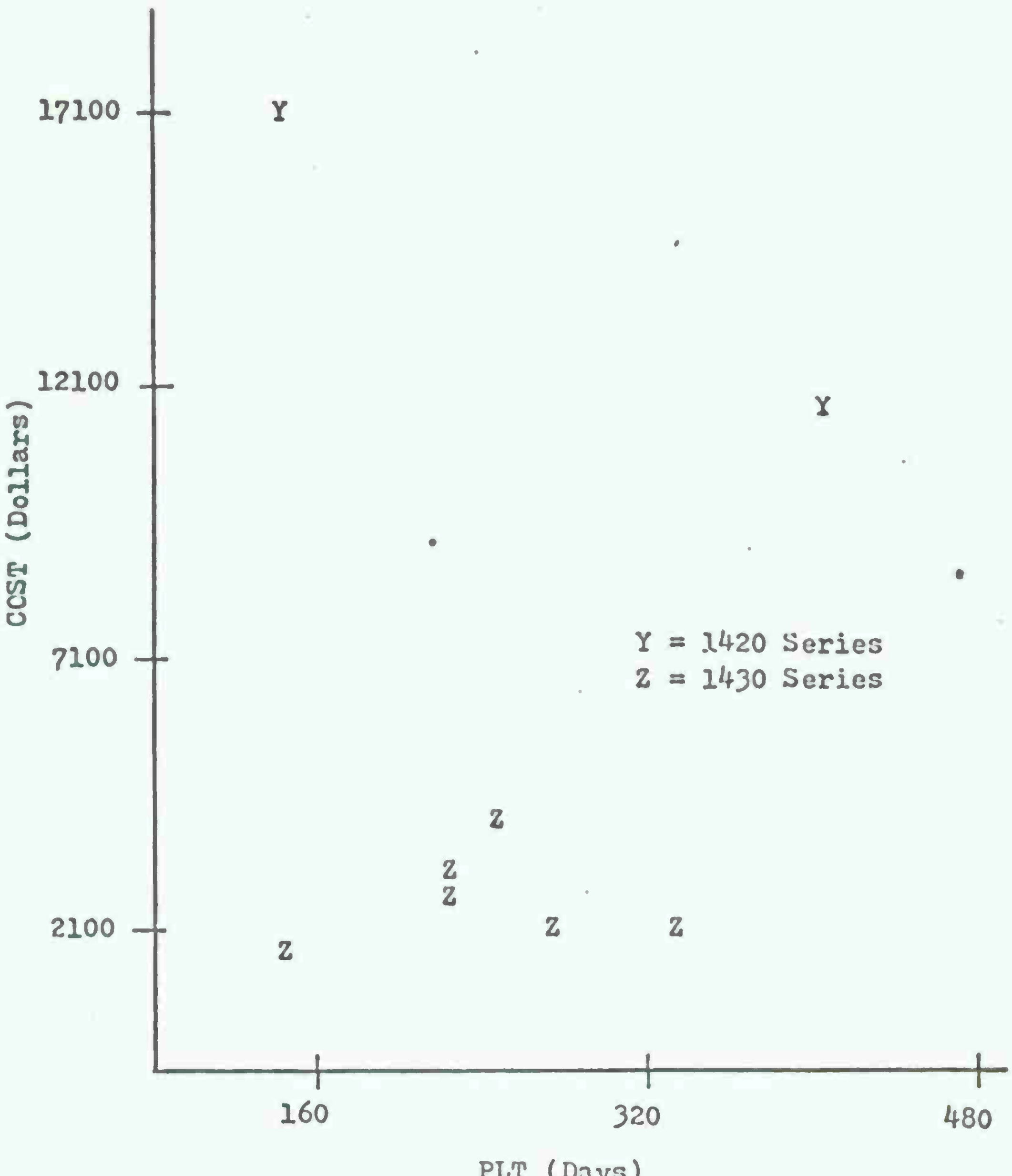

Figure 24 Scatter Plot of COST versus PLT for Level 'B' of UNITZ, Differentiated According to Federal Stock Number Series.

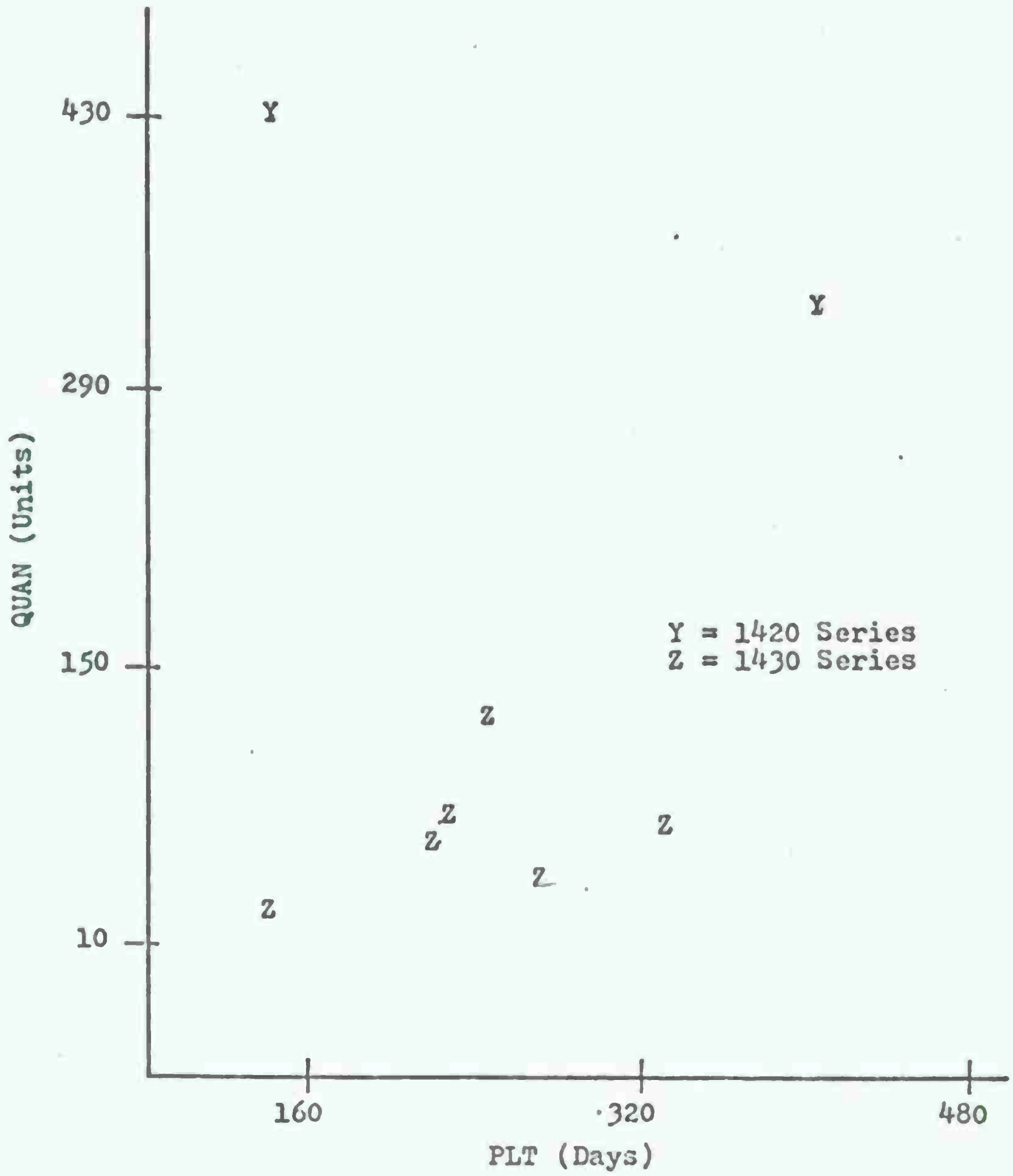

Figure 25 Scatter Plot of QUAN versus PLT for Level 'B' of UNITZ, Differentiated According to Federal Stock Number Series.

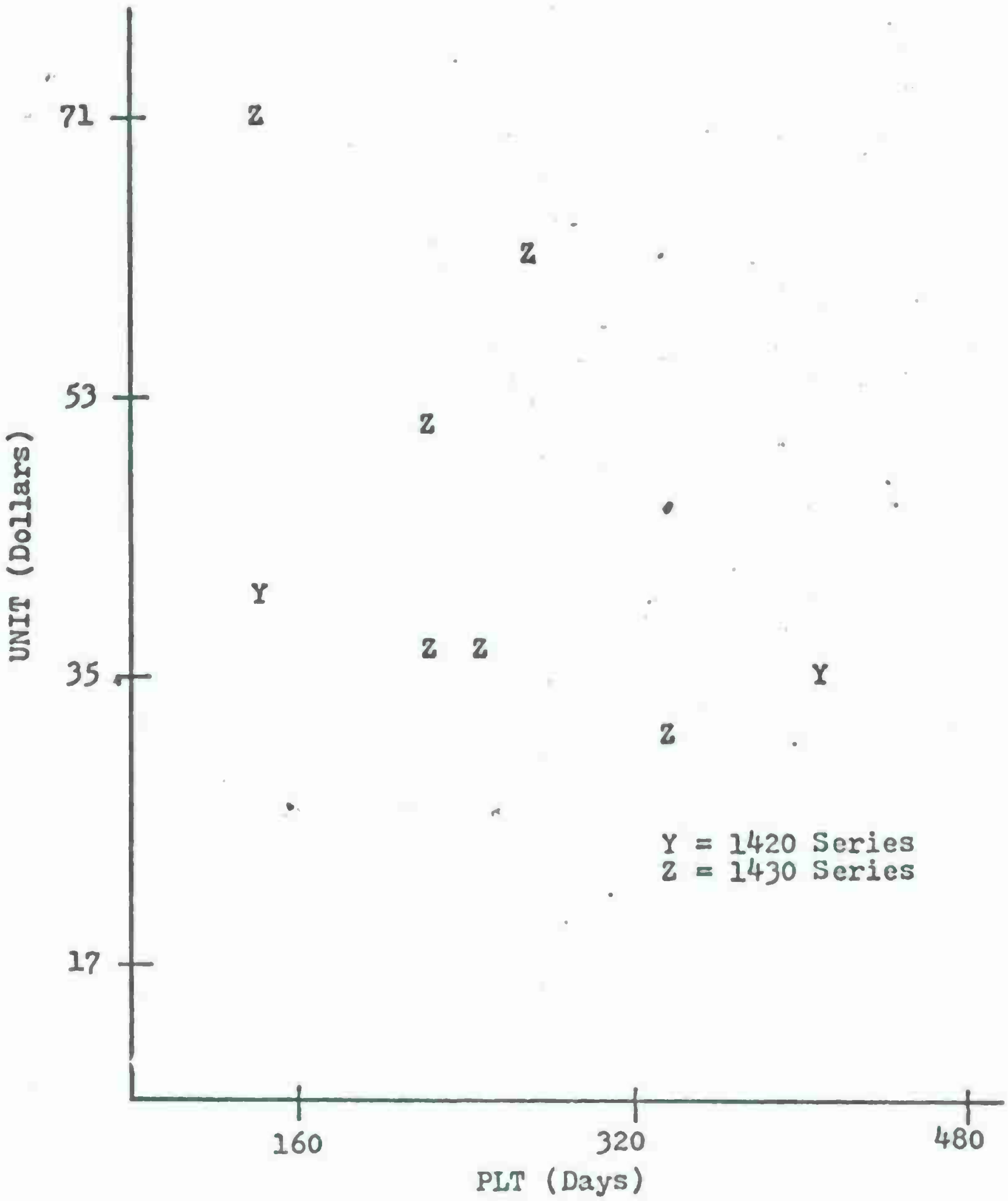

Figure 26 Scatter Plot of UNIT versus PLT for Level 'B' of UNITZ, Differentiated According to Federal Stock Number Series.

Table 9 Regression Coefficients for Levels of Dummy Variable UNITZ.

MODEL

$$PLT = b_0 + b_1 * QUAN + b_2 * COST + b_3 * UNIT + \epsilon$$

LEVEL 'A' REGRESSION COEFFICIENTS

b_0 = 142.138
b_1 = -0.345
b_2 = 0.071
b_3 = -6.181

LEVEL 'B' REGRESSION COEFFICIENTS

b_0 = 221.656
b_1 = 4.751
b_2 = -0.126
b_3 = 1.016

LEVEL 'C' REGRESSION COEFFICIENTS

b_0 = -7452.864
b_1 = 295.234
b_2 = -3.520
b_3 = 91.842

LEVEL 'D' REGRESSION COEFFICIENTS

b_0 = 1183.926
b_1 = -89.840
b_2 = 0.861
b_3 = -9.371

Table 10 Actual and Predicted Lead Times in Days Using the Models Developed.

ACTUAL PLT	PREDICTED PLT	RESIDUAL	LOWER 95 CL	UPPER 95 CL
		BY LEVEL 'A'		
73.0	51.8	21.2	0.0	127.5
120.0	112.1	7.9	66.6	157.5
56.0	103.6	-47.6	47.9	159.4
190.0	118.5	71.5	59.9	177.0
105.0	116.4	-11.4	37.6	195.2
69.0	125.4	-56.4	74.2	176.6
180.0	151.1	28.9	107.0	195.2
183.0	186.6	- 2.6	96.7	274.6
149.0	162.4	-13.4	101.1	223.8
556.0	553.8	2.2	444.0	663.6
		BY LEVEL 'B'		
137.0	200.8	-63.8	58.2	343.3
268.0	198.0	70.0	99.7	296.2
328.0	307.9	20.1	192.0	423.8
218.0	269.4	-51.4	173.8	365.1
218.0	170.5	47.5	71.6	269.5
240.0	273.8	-33.8	192.8	354.7
403.0	376.0	27.0	208.8	543.3
136.0	151.4	-15.4	0.0	322.6
		BY LEVEL 'C'		
212.0	277.9	-65.9	0.0	630.3
216.0	179.5	36.5	0.0	463.7
153.0	199.0	-46.0	0.0	501.6
337.0	249.9	87.1	0.0	510.8
423.0	192.4	30.6	0.0	790.7
262.0	304.2	-42.2	0.0	687.1
		BY LEVEL 'D'		
173.0	169.9	3.1	153.2	186.7
115.0	118.7	- 3.7	100.4	136.9
159.0	160.8	- 1.8	139.9	181.7
130.0	125.7	4.3	108.2	143.2
289.0	288.0	1.0	268.4	307.6
214.0	216.8	- 2.8	201.5	232.1

CHAPTER V

CONCLUSIONS

This investigation on PLT for missle repair parts contracts dealing with cable assembly and wiring harnesses has produced several results. However, it is to be noted that this investigation was conducted with insufficient data, and the models obtained to predict PLT should be treated with caution. The models have not been validated, and further investigation is recommended before using them to predict PLT on future contracts.

The following results were noted:

1. Total contract cost had the single largest influence on PLT. Total contract cost possessed even greater influence when regressed by interval ranges of unit purchase prices.

2. PLT variability was found to be considerable. Therefore, models used to predict PLT will have wide confidence intervals. It is felt that as more information is acquired for an item, these confidence intervals can be reduced.

3. More information is needed on the physical appearance and special characteristics of the cable assemblies. A set of complexity factors need to be incorporated to provide this information. Codes should be established to differentiate the length of the assemblies, the number of individual wires in these assemblies, whether the wires are color coded, the materials involved, and whether the cable assemblies are shielded. This information would add emphasis to variable UNIT's relation to PLT.

4. Analysis of this cable assemblies with regard to Federal Stock Number Series showed significant trends between series. This could possibly be a basis for further investigation of PLT along these lines.

5. There are several qualitative aspects that affect PLT. Although not considered in this investigation, they include the economy of the nation, the energy crisis, shortages of materials, and national consumer trends. It is felt that they have a definite bearing on the increase of PLT over the past few years.

RECOMMENDATIONS

As a result of this investigation several possible avenues for further research has been opened. Several of these research topics could not be properly studied in this paper due to total lack of data or insufficient quantities of data. These recommendations are as follows:

1. An important area for investigation should be the establishment of some type of Computer Information System to store and implement the key data of importance. A computer program could be written to set up computer files on all seventeen categories to provide efficient means of retrieval of data information as needed. This would probably be a complex undertaking, but one that would be of great benefit for any subsequent research performed on PLT. The present computer files just do not have the kind of information needed to perform a thorough and efficient investigation.

2. The Complexity Codes discussed in the Conclusion should be established and implemented.

3. Several new variables should be examined for their effects on PLT. These variables include ALT, PRLT, missle system, type of procurement, contractors previous performance record, and the contractors capabilities regarding facilities, equipment, personnel, and financial stability.

4. Analysis of PLT by intervals of unit price, quantity, and total contract cost should be investigated further. A data base of at least 100 to 150 contracts be used in any further investigation on PLT.

5. Analysis of PLT by Federal Stock Number Series should be performed. Significant trends were discovered using this technique in this investigation.

6. Contracts involving First Article production should be investigated in a separate analysis.

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